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THE DEVELOPMENT OF DISCRIMINATION IN A SIMPLE LOCOMOTOR HABIT [1]

BY WILLIAM S. VERPLANCK

Brown University

The present experiment is concerned with the course of acquisition of a simple discrimination habit in the white rat, and with the relationship of that course to the phenomena resulting from the simple reinforcement and non-reinforcement of responses to differing stimuli. Recent emphasis, theoretical and experimental, on the acquisition of discriminations in the choice-reaction situation, the 'instrumental' or 'operant' conditioned response, and the conditioned reflex has made a trial-by-trial description of the process desirable. The data obtained clearly indicate that the principles first observed in studies of the conditioned reflex are parallelled to a striking extent in the more complex behavior obtained by means of a quite different set of operations.

A number of experiments (from the Brown laboratory) have been concerned with that form of behavior which has been variously termed 'operant conditioning,' 'trial and error learning,' 'problem solving,' and 'Thorndike's rewarded learning.' The response which has been investigated is that of running down a small runway to a food box when the door of a starting box has been opened. The latent period has been chosen as a measure of the strength of the response. This is defined as that interval, measured to the nearest fifth of a second, between the opening of the door and passage across a mark four inches beyond the door of all except the animal's tail. The course of acquisition, extinction, and spontaneous recovery of the response has been studied (**6**). Data on the effect of spacing of trials (**4**), on retention after primary acquisition and extinction (**5**), and on external inhibi-

[1] This paper was presented as a thesis to the Faculty of the Graduate School of Brown University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology, June 1941. The author is indebted to Professor C. H. Graham of Brown University, under whose direction the present research was carried out.

tion and disinhibition have been collected (3). The effect of random reinforcement on subsequent extinction has been determined (2), and in the experiment here reported it is the course of acquisition of discrimination which has been investigated.

It is possible to analyze any extended sample of behavior into a series of correlations of stimulus and response, termed 'reflexes,' or '*S-R* bonds.' When such analysis is made, it is found that such reflexes are chained, that is to say, the response to one stimulus may serve to produce the stimulus to the next response. This linkage may occur in either of two ways: (1) the response may set up internal stimulation which elicits the next response, or (2) the response may so move the organism with respect to the environment that new external stimuli may act upon the organism's receptors, thus eliciting the next response.

Any such chain of stimulus-response correlations can be reinforced, and the strength of each member consequently augmented. But it has been found that all members of a chain are not affected alike by reinforcement at the termination of the chain. Most prominent of the differences which may occur is this: The more remote from reinforcement the occurrence of a correlation, the less the augmentation of its strength. This effect has been most extensively treated by Hull (11) in his work in the goal gradient. Skinner (14) has also discussed the problem.

The behavior studied in the present series of investigations constitutes such a chain of correlations, and the member of the chain whose strength was studied may be denoted as the response of running out on the alley, which is elicited by the change produced by the opening of the door in front of the starting box. In an extensive series of preliminary and purely exploratory experiments carried out in the academic year 1939–1940, it was found that a later member of the chain displayed many interesting properties, and that a second measure was necessary for an adequate description of the development of discrimination. The stimulus of this correlation is specified as the environmental and internal energy-changes which affect the organism as it runs down the alley to the food box, and the response is full entrance into the food box. The measure which has been made is termed *running time*, and is defined as that interval, in seconds, between the termination of the latent period, and the time at which the animal has entered the food box to such an extent that when the door of the food box is closed, only the tail of the animal remains outside. This measure is taken to represent the latent period of the second reflex.

When these considerations have been taken, it will be evident that when experimentally introduced discriminative stimuli are present at the opening of the door and through the remainder of the apparatus,

the behavior displayed consists of two chains of correlations. And furthermore, in measuring the latent period and the running time the strengths of two separate stimulus-response correlations in each chain are determined. Diagrammatically, we may present the situation as follows:

Chain A:

S	——	R	- - - - - - -	S	——	R	- - - - - -	S	——	R,	
door opening D alley		running out		D alley and food box		entrance in food box		food		eating	

Chain B:

S	——	R	- - - - - - -	S	——	R	- - - - - -	S	——	R,	
door opening Δ alley		running out		Δ alley and food box		entrance in food box		food		eating	

where D and Δ are the discriminative stimuli.[2]

The present problem, then, may be stated as follows: to determine the course of changes in strength of two members of each of two chained correlations of stimulus and response as a function of differential reinforcement of the chains.

Method

Apparatus

The runway described by Graham and Gagné (6) was employed, with certain modifications. A longitudinal diagram is presented in Fig. 1.

This runway has the dimensions $3' \times 2'' \times \frac{3}{4}''$. One end is attached by a swivel arrangement to a point just below the center of the sill of the door to the food box; the other end, loose, is bevelled to fit into a notch cut into the base of the starting door. This loose end is firmly held in its groove by a rubber roller, under considerable tension from a strong spring. A pulley and rope arrangement attached to the holder of the roller enables the experimenter to release the runway and to rotate it about its longitudinal axis. Of the two running surfaces of the runway, one is painted black, one white; the sides are gray.

The gray permanent starting box has the outside dimensions $5\frac{1}{2}''$ wide, $7\frac{1}{4}''$ long, and $4\frac{3}{4}''$ high. It is open at both ends, and the top is covered with a wire screen. One open end fits against the frame of the starting door; the other may be closed by a door hung from below on a stiff hinge. Three food boxes were utilized, one white, one black, and one gray. (The latter was used in preliminary training.) Aside from brightness, they are identical. The outside dimensions of these boxes are $5\frac{1}{2}''$ wide, $7\frac{1}{4}''$ long, and $5''$ high. The top is screened, and one end is open. The open end fits against the frame of the door through which the animal passes. On the closed end is the food receptacle which is a metal shelf $1\frac{1}{2}''$ wide, $1''$ deep and $\frac{5}{8}''$ above the floor. The front of this shelf is screened by a piece of metal $1\frac{1}{2}''$ wide and $1''$ high. A hole cut in the back of the box permits the loading of this shelf, and examination of its contents. A handle is attached to the box above the hole.

The doorways, $5\frac{1}{2}'' \times 5\frac{1}{2}''$, are cut in the center of the lower face of large screens at each end of the runway. These screens are permanently built on the box holders and door frames, and

[2] Such an analysis of the behavior under investigation may be open to question as a gross over-simplification. The writer is fully aware of this vulnerability to criticism, but accepts it nonetheless in view of its ready submissibility to experimentation and of the adequacy of its description of the behavior observed and results obtained.

are painted gray. The doors themselves are likewise gray, and open to a height of 5". They can be quietly and rapidly raised or lowered by a pulley, string, and counterweight arrangement manipulated by the experimenter.

The whole apparatus is enclosed in a large wooden framework, covered by cheesecloth, which forms an effective one-way screen. The only illumination is provided by a 25-watt bulb about one foot in front of the screen at the food box end of the runway, and 20" above the runway.

The experimental room is in a part of the building which is quiet at night, when the experiments were conducted.

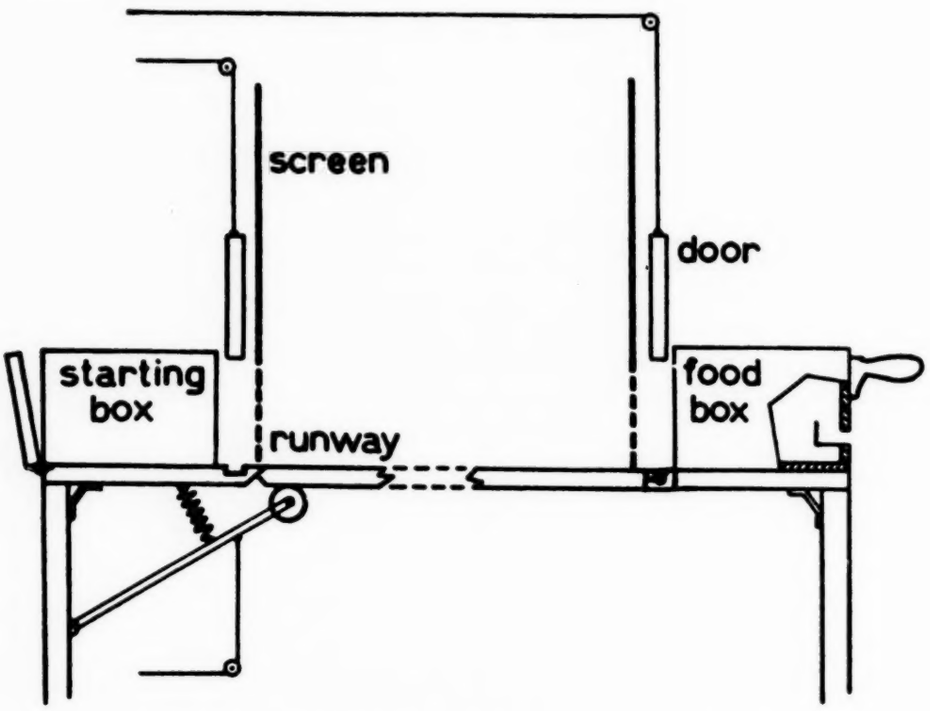

FIG. 1. Representation of the apparatus employed.

Accessory apparatus included a nine-foot section of elevated runway of the same width as the experimental alley. This is painted black and white in different sections and was used in preliminary training. Two platforms, approximately one foot by one foot were employed, one for feeding after a day's experimental session, and one for those periods when the animal waited to be used or to be returned to the living cage.

PROCEDURE

1. *Preliminary Training*

Several days prior to the beginning of preliminary training, each subject was taken off the usual unrestricted food regime employed in the rat colony, and was placed on a feeding schedule. On this schedule, each rat was permitted to eat for one-half hour every day the small cylindrical pellets of Purina dog chow employed in the experiment.

On the first day of preliminary training, the rat was taken to the experimental room and placed on the practice runway, where he was permitted to run for 10 minutes without reinforcement. He was then placed on the waiting stand for at least one minute, after which he was held in the experimenter's hand for five minutes. After another one-minute wait, he was placed in the practice food box for five minutes without reinforcement. The order in which the last two parts of the training occurred was often inverted. Finally, after another delay, the animal was placed on the food stand and allowed to eat and drink for twenty minutes. On the third habituation day, the five minutes' handling was dropped, and approximately twenty small pieces of food were given in the food box. After the animal had eaten these, and after a short stop on the waiting stand, he was placed on the food stand and allowed to remain there until he had spent a total of twenty minutes eating. The regime of feeding twenty minutes a day, including the time

of reinforcement, was maintained throughout the course of the experiment. It is believed that this procedure of setting up and maintaining a feeding schedule held the subjects' drive at a relatively constant level throughout the experiment. The rats employed remained healthy through the experimental period although some loss of weight was observable occasionally.

2. *Initial Acquisition of the Running Behavior to Black Alley and Food Box*

On the first day of the experiment proper, eight reinforced trials were given on the black runway with black food box. The procedure employed was as follows. Two minutes before the start of the trial, the animal was placed in the starting box. The food box was baited with a quantity of food which required approximately one and one-half minutes to eat (*ca.* 0.35 gm.). This amount varied slightly from animal to animal. At the beginning of the trial a stopwatch was started as the starting door was opened. At the moment when all the animal's body except the tail had crossed a point three inches from the starting box, the watch was stopped, and another started. As soon as the animal had traversed the runway and entered the food box according to the criterion of entrance (*vide supra*), the door was closed and, at the same time, the second watch stopped. As soon as the time on the first watch (latent period) had been read to the nearest fifth of a second, the watch was reset and restarted, a procedure which took not more than two to three seconds. The latent period and running time were now recorded. At the end of one minute, the runway was released by the experimenter in such a manner that a sound similar to the noise of reversing the runway was produced. At about the same time, the door to the starting box was closed. At one minute and twenty-five seconds, uneaten food was taken from the food box, and the box was carried to the other end of the apparatus. The experimenter now transferred the animal to the starting box. The food box was returned to its original position and reloaded. About two seconds before the end of the two-minute interval, the stopwatch was stopped, reset, and the next trial was begun.

3. *Discrimination Training*

During the main course of the experiment, every *fourth* trial was reinforced. Thus, training was divided into what may be termed *cycles* of three non-reinforced trials followed by one reinforced trial. The trial procedure in this section of the experiment was the same as in initial acquisition of the black habit, with the following exceptions: (1) Immediately before and after a reinforced trial, the alley was turned over, and the food box was changed after the animal had been transferred to the starting box (except in the case of Group III). (2) Food was placed in the food box only before positive trials. Before negative trials the experimenter went through the motions of loading, thus counterfeiting the attendant sounds. (3) If after two minutes[3] from the inception of the measurement of latent period the animal had not left the starting box, the door was closed, and the watch was reset and restarted. The latent period for such a trial was arbitrarily recorded as 'infinite.' In the thirty-second period immediately thereafter, the runway was manipulated, and the food box appropriately handled. At the thirty-second interval the door was opened for the next trial. Finally, (4) if, after two minutes from the inception of the measurement of running time the animal had not entered the food box, he was taken from wherever he might be, and placed in the starting box, the door to which was then closed. From this point, the same procedure was carried out as in (3) above. Under the conditions of (4) running time was recorded as 'infinite.'

The training of the four experimental groups was as follows:

For Group I, six cycles daily for four successive days of three trials unreinforced on the black alley and black food box; one trial reinforced on the white alley and white food box.

For Group II, six cycles daily for four successive days of three trials unreinforced on the white alley and white food box; one trial reinforced on the black alley and black food box.

For Group III, six cycles daily for four successive days of three trials unreinforced, one trial reinforced, all on the black alley and black food box.

For Group IV, four cycles daily for six successive days of three trials unreinforced on the black alley and black food box; one trial reinforced on the white alley and white food box.

Groups I and II are the fundamental groups, in that they offer the possibility of comparison of acquisition of discrimination under two conditions: (1) where the initially strong chain is

[3] See exception, p. 458.

extinguished and the related chain reinforced (Group I); and (2) where the initially strong chain is reinforced and the related habit extinguished (Group II). Fifteen rats were run in each group.

Group III offers an important control on (1) the possibility of the development of a temporal discrimination, and (2) the effect produced when generalization of reinforcement and non-reinforcement is necessarily complete. Seven rats were utilized.

Group IV was run with a view to examining for possible effects of massed practice. Nine rats were run in this group.

Each rat's daily run, with exceptions to be noted below, began within one-half hour of 24 hours after the beginning of the preceding day's run. However, in the cases of four rats in each of groups I, II, and III, and one rat in Group IV, a lapse of 48 hours occurred between one pair of daily runs. These rats were fed 20 minutes on the intervening day. None of the records of these animals shows any appreciable differences from the records of the other animals in the same group which could be attributed to the longer interval.

The Animals

Seventy-one male albino rats, members of the inbred Wistar strain which constitute the colony of the Psychological Laboratory were used in the present experiment. Of these, twenty-five were discarded, ten for failure to leave the starting box on the first trial of initial acquisition, eight for failure to run on a positive trial, either in the initial training series or in a positive trial of the first few discrimination cycles, and four because of error in experimental handling.

The animals were obtained from thirteen litter groups, each constituted of double first cousins, and the members of each experimental group were drawn as evenly as possible from all litter groups. The average ages of the rats in each group on the day on which discrimination training started were: Group I, 82 days; II, 82 days; III, 84 days; IV, 83 days. The experimental group membership of any individual rat was not decided until after initial acquisition training was complete, and then was determined by lot. This ensured that the groups were comparable.

The experiment was carried out through the fall and winter of 1940–1941.

In summary, the following important variables have been held constant for all groups: drive, amount of reinforcement, trial interval, initial response strength, and environmental stimulation. Magnitude of response has been measured as a function of the correlation of reinforcement and non-reinforcement with the discriminative stimuli.

Results

General

In accordance with the procedure of Graham and Gagné (**6**) all measurements have been converted into logarithms. The rationale of this conversion has been fully discussed elsewhere (**6**), and need not concern us here.

Since the failure of response to occur within two minutes has been arbitrarily recorded as representing a latent period or running time of 'infinite' duration, it was not possible to determine a mean log latent period and mean log running time for many non-reinforced trials. However, means have been computed for (1) all reinforced trials, (2) the initial trial of any day, and (3) (in Group III) especially a sample of unreinforced trials, where an 'infinite' measure was not obtained. The median has been determined for all trials.

Examination of the data shows that the median of the measurements closely approximates the mean of the logarithmic distributions. From consideration of this close similarity of the measures, the validity of the conversion of raw data to logarithmic values appears evident. The median, then represents satisfactorily the central tend-

encies of the distributions obtained. Similarly, the quartile deviation was determined instead of the average deviation. Where Q_3 was measured as infinite, it was not, of course, possible to measure the quartile deviation, so the value (Median-Q_1) was employed.

In the light of these considerations, and because the median is the only measure of central tendency available on all trials, the graphs and discussions presented will be based upon the median values.

The Data

1. *Complete Graphs.*[4]

Figures 2 and 3 present learning curves for each of the four groups.[5] On each graph, the vertical lines show the point at which each day's

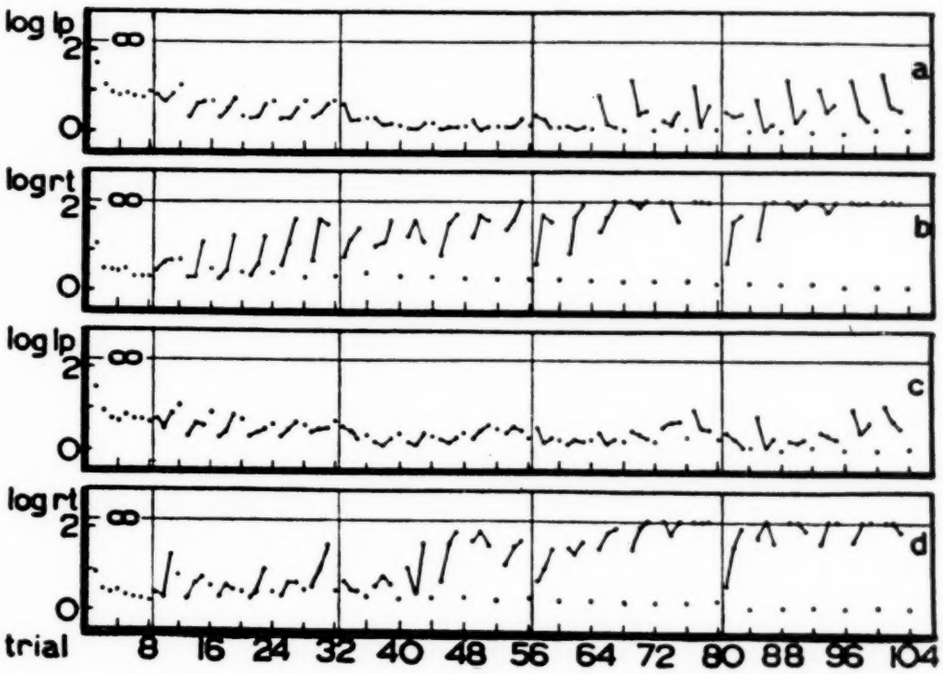

FIG. 2. Complete learning curves, Groups I (B−, W+) and II (B+, W−). The vertical lines separate daily runs. "Infinite" latent periods and running times are arbitrarily plotted on the horizontal line at the top of each graph. This is identified by the infinity sign which interrupts it. The logarithms of the measures are plotted as a function of the number of reinforcements and non-reinforcements.

a. Group I, median log latent period.
b. Group I, median log running time.
c. Group II, median log latent period.
d. Group II, median log running time.

training ceased. A horizontal line which is marked '∞' and which originates approximately at the ordinate value of 2.08 log units (120

[4] Complete tables, including the means, average deviations, and quartile deviations calculated, are obtainable in the John Hay Library of Brown University.

[5] Such curves for individual animals do not differ in any significant respect from the group curves. Curves for each animal may be obtained by application to the writer.

seconds) has been introduced so that the data on trials on which the latent period or running time were 'infinite' may be plotted. This arbitrary procedure is necessitated by the demands of clear presentation. Points on this line do not rigorously constitute measures of either latent period or running time.

Examination of the curves indicates clearly the progressive and orderly changes in the strength of the two habits with training. There is no evidence of the abrupt appearance of a marked difference in their

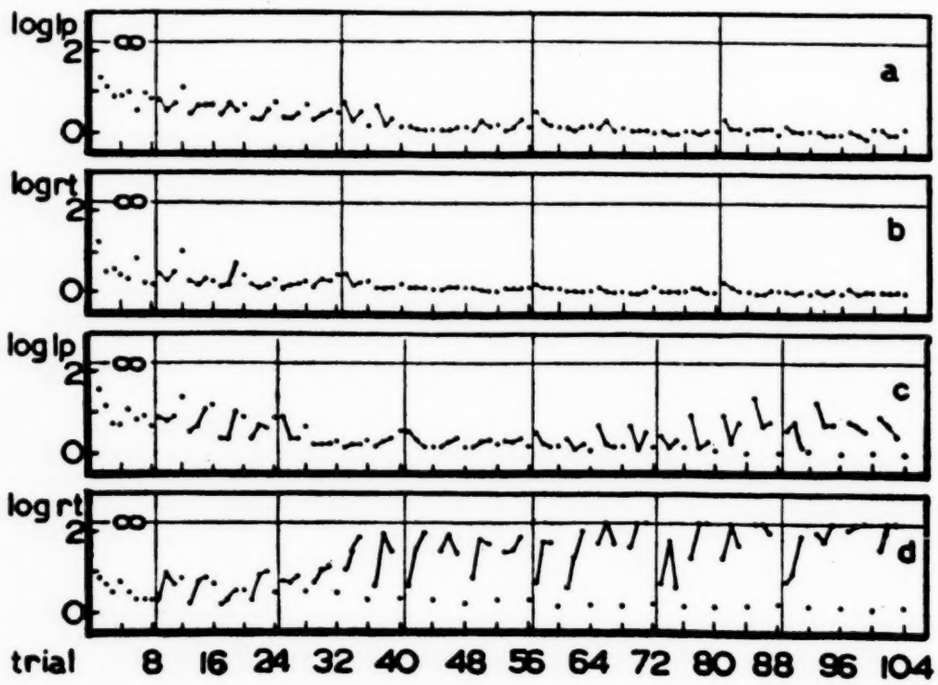

FIG. 3. Complete learning curves, Groups III (B+, B−) and IV (B−, W+). The vertical lines separate daily runs. 'Infinite' latent periods and running times are arbitrarily plotted on the horizontal line at the top of each graph. This is identified by the infinity sign which interrupts it. The logarithms of the measures are plotted as a function of the number of reinforcements and non-reinforcements.

a. Group III, median log latent period.
b. Group III, median log running time.
c. Group IV, median log latent period.
d. Group IV, median log running time.

strengths, no evidence of 'insightful' behavior, nor does any individual record display any of these characteristics. In Group III (B−, B+),[6] there is clearly no differential behavior with respect to positive and negative trials as such; in Groups I (B−, W+), II (W−, B+), and IV (B−, W+) the curves for log running time indicate that discrimination proceeds in general as the simultaneous acquisition of one response with extinction of the other. The log latent period curves,

[6] The parenthetical expression indicates the training on each cycle. The capital letters refer to the color of the alley and food box; the '+' and '−' signs indicate respectively the stimulus conditions, response to which is reinforced or unreinforced.

however, show that discrimination in the earlier member of the behavior chain (running out of starting box) proceeds more slowly than the later member (running to food box), and perhaps through a mechanism different from that of simple extinction.

2. *Initial Acquisition and the First Cycle.*

In Figs. 4 and 5, to the left of the black line, are presented graphs showing initial acquisition of the two responses on the black alley and

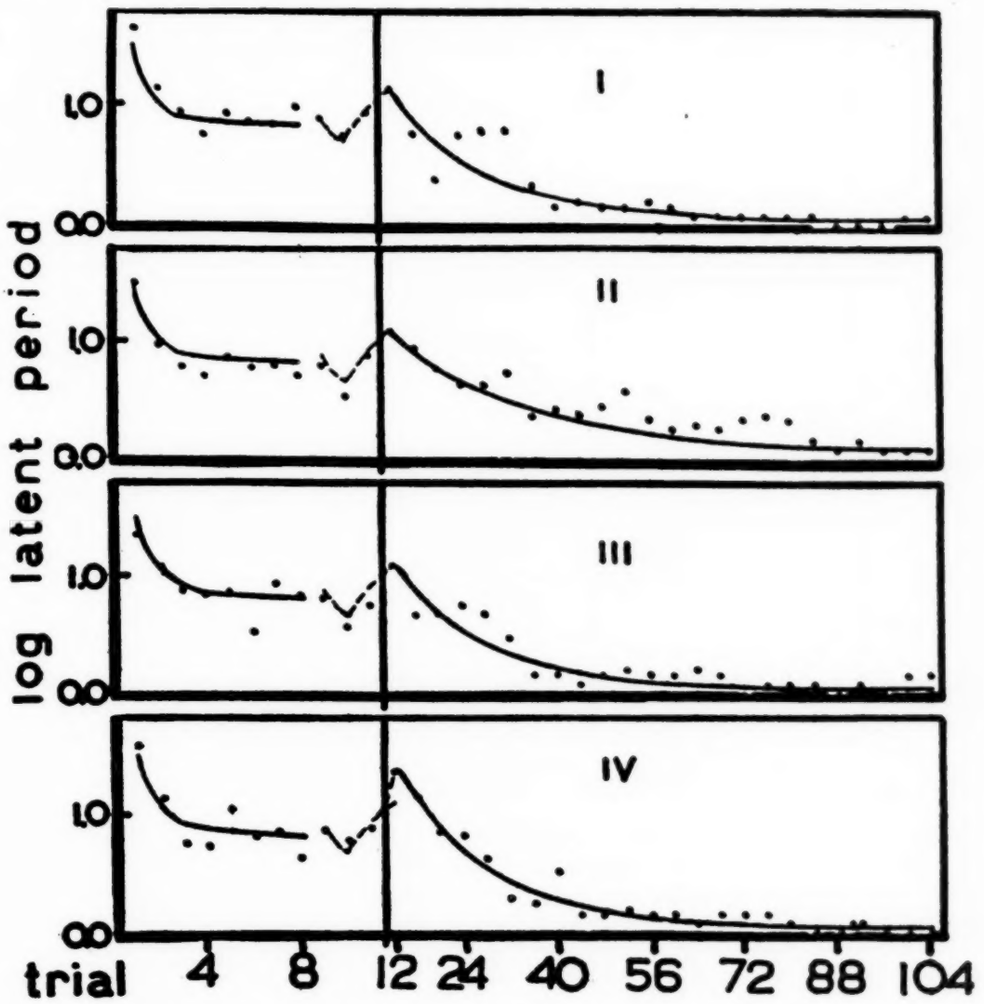

FIG. 4. The acquisition of the response to the positive stimulus which is measured by log latent period. To the left of the black line median times for the first 12 trials, reinforced and unreinforced, are plotted. To the right, only the magnitude of response on the *positive* trials is plotted. The curves are visually fitted to the data.

food box, and the course of response during the unreinforced trials of the first cycle of discrimination training.

a. Latent Period.—Under the present conditions of reinforcement, the latency of the running-out response reaches, in the course of four trials, a stable level of 6.3 seconds from the initial time of approximately 32 seconds. This 5 : 1 decrease is not so great as is found

under other conditions for the same number of trials (4, 5). The form of the curve, however, approximates that found by Gagné under somewhat similar conditions.

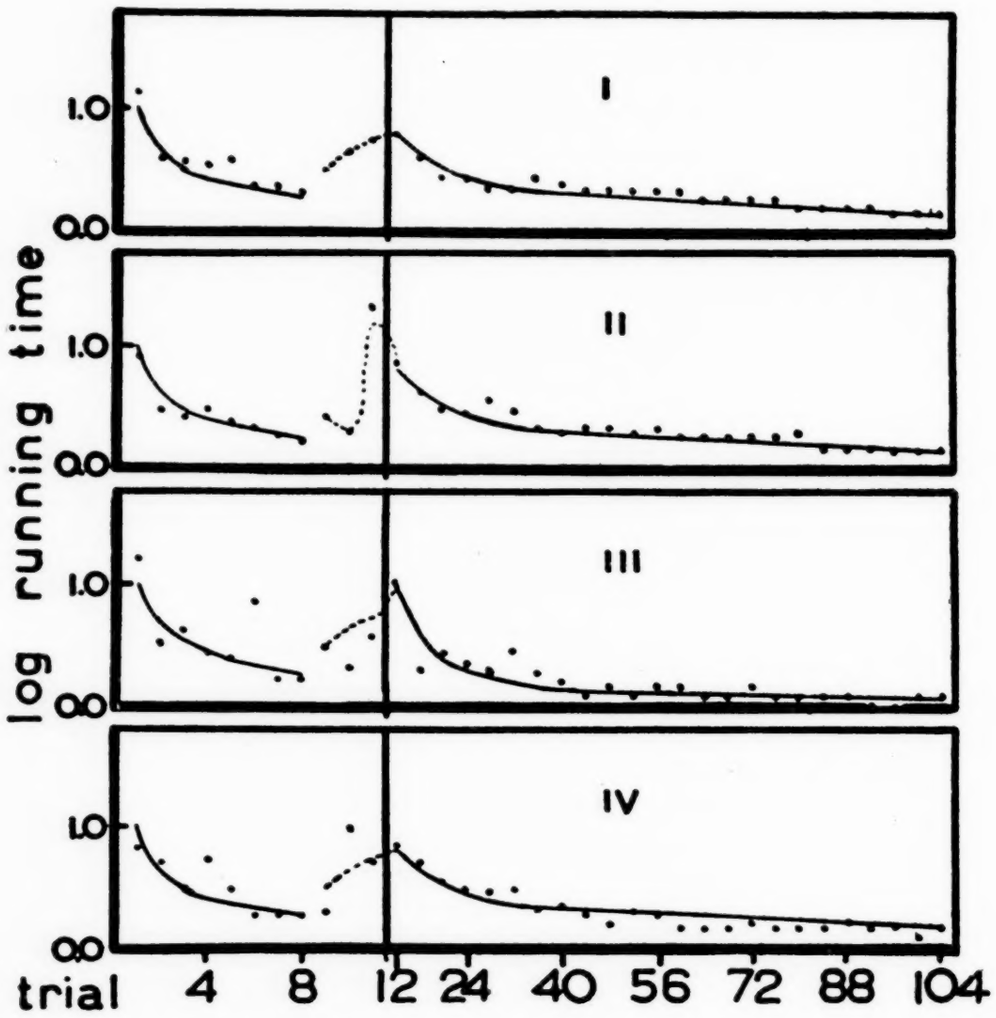

FIG. 5. The acquisition of the response to the positive stimulus which is measured by log running time. To the left of the black line, median times for the first 12 trials, reinforced and unreinforced, are plotted. To the right, only the magnitude of response on the *positive* trials is plotted. The curves are visually fitted to the data.

There are a number of significant findings in the data for all groups for the first cycle. They are:

1. There are no significant group differences on the first three unreinforced trials despite the fact that the white alley and food box are now presented to members of Group II.
2. On the first unreinforced trial, the median latent period for all groups is almost identical with that of the last trial some 24 hours before.
3. After one non-reinforced trial, all groups run more rapidly. Subsequently, extinction takes place.

4. On the 12th trial (the first reinforced trial of the first discrimination cycle), there are no differences between the groups which are attributable to the experimental handling. The considerably slower time shown by Group IV on this trial is certainly significant, as will appear later, but the writer can give no account of it. This group, it should be emphasized, has had to this point precisely the same handling as Group I. However, there is no evidence of discrimination. After the first trial, the form of the curve is like that described by Gagné (**6**) in extinction. The form of the extinction curve (trials 9–11) suggests that the 24 hours intervening between acquisition and extinction introduce complications which must be described in any theoretical account. Discussion of this effect is reserved.

b. Running Time.—Through the course of eight trials, the running time drops in a regular manner from 10 seconds to 1.8 seconds, a change of 5.6 : 1. This is but slightly larger than the similar ratio for the latent period. However, the running time has by no means reached a stable level. The curve of acquisition for running time, furthermore, is different in form from that of latent period; it is not possible to fit both data with the same curve.

Striking differences seem to appear in the first cycle, despite the fact that all four groups start with approximately the same running time of some 2.8 seconds and that through trials 9, 10, and 11, Groups I, II, and III have identical handling. However, examination of the distribution determining each point for the four groups on trials 10 and 11 indicates that the apparent differences in these groups are artefactual. Accordingly, the data have been visually fitted with curves which describe them satisfactorily. The observations then may be summarized:

1. Groups I, III, and IV systematically extinguish over the first cycle. However, Groups I and IV run more rapidly in the presence of the new discriminative stimuli than does III, which continues on black. This difference might be expected from the phenomena of generalization of the effects of non-reinforcement.

2. Group II clearly behaves differently from the other groups on trials 10 and 11. On trial 10, it runs faster than the others, and, indeed, faster than on trial 9. In this respect, its behavior resembles that of all groups in latent period. Further, after the 2d non-reinforcement, its time is strikingly longer—*RT* (for trial 11): *RT* (for trial 10) = 11 : 1. And with the presentation of the discriminative stimulus, there is an equally striking speed-up of the order 3 : 1. This group, then, seems to respond differentially on the first presentation of the positive stimulus, after extinction of response to the negative.

In summary, Groups I and IV show a slight differentiation of re-

sponse to the newly introduced stimuli; Group II displays discrimination to a marked degree.

3. *Changes of Strength in Response to the Positive (Reinforced) Stimulus.*

The graphs of Figs. 4 and 5 present, to the right of the vertical black line, for each group, the changes occurring in latent period and running time as a function of number of reinforcements of the positive stimulus. Thus the unreinforced trials of each cycle are omitted. The adequacy of the fits is evident.

a. Latent Period:

1. The same curve fits the data of Groups I, III, and IV. For Group IV, the curve is shifted one cycle to the left, in order to fit the initial point. Groups I, III, and IV have in common the following history: initial training on black alley, black food box followed by non-reinforcement on black alley, black food box.

2. Group II, which continues to be reinforced on black, shows consistently slower improvement, a finding suggestive of greater generalization of the effect of non-reinforcement from the weaker response to the stronger. This is consonant with Williams' (**16**) findings in an experiment on the interaction of habits differing slightly in both stimulus and response.

3. Systematic deviations from the fitted curves appear in Groups I, II, and III. These appear only for the last two or three positive trials of any day. Such deviations, with one exception, do not appear in the data of Group IV. The exception is on the last positive trial of a day's run. Group II shows this effect most persistently.

4. At the end of the present training, all groups have come to a final stable level.

b. Running Time:

1. The same curve fits the data of Groups I, II, and IV.

2. The curve of Group III, where there is no discriminatory stimulus, shows a much more rapid decrease in running time. The cumulative effect of the reinforcements, then, is greater for these animals.

3. At the end of training, Group III alone has reached a final stable level of performance.

4. *Changes of Strength in Response to the Negative Stimulus.*

The changes in strength of the responses to the negative stimuli are more complicated than those to the positive. Intervening between presentations of the positive stimuli are one reinforcement of

the positive and three non-reinforcements of the negative stimulus. Between successive presentations of the negative stimuli there is no such consistency. Although between every pair there occurs one non-reinforcement of response to the negative stimuli, between every third pair there also occurs a reinforcement of response to the positive. Consultation of the learning curves (Figs. 2 and 3) shows that this difference in treatment has two effects. The first is to increase on the first trial of a cycle the strength of the response measured by running time throughout the training, and the strength of that measured by latent period in only the earlier part of the training. The mechanism whereby this occurs seems to be generalization of reinforcement. Performance on subsequent negative trials takes the form of an extinction curve. A reversal of effect occurs in the response measured by latent period in the latter section of training. Despite this complication, it is necessary to make arbitrary measure of the general level of response to the negative stimulus through each cycle. The median log latent period and median log running time of all runs in response to the negative stimuli in each cycle have been found satisfactory for the purpose. These values are plotted in the graphs of Fig. 6.

Examination of these data shows conspicuous day-to-day effects. One such effect has been found previously in the present experiment: In the fifth and sixth cycles of the first days of training, there appears in the latent period measure of Groups I, II, and III a decrement in response to the positive stimulus which disappears over night. This finding appears to hold for the same measure of response to the negative stimuli; the persistence of the effect in Group II also occurs here. The writer is not prepared to state whether this effect is a consequence of the experimental manipulation of reinforcement and non-reinforcement, or of failure of complete adaptation to the handling which was necessary on every trial. The former interpretation is the more probable.

A second effect, which is seen most clearly in the present data on Group III, is what has been termed 'warming-up.' This phenomenon is more striking in the latent period measurements. The first few trials of any day show progressive decreases in both latent period and running time which are not attributable to reinforcement. Similar observations have been made in both conditioning (**12**) and learning (**1**). It has been considered a phenomenon of circular conditioning (**7**).

The third day-to-day effect, which may be identified as spontaneous recovery, is a marked over-night increase in the strength of response to the negative stimulus after discrimination has begun. Graham and Gagné (**6**) have found that spontaneous recovery occurs in the present situation over the course of ten minutes after extinction, but the degree of such recovery was limited. Hovland (**10**) has found

that such spontaneous recovery occurs in conditioned responses which have been subjected to secondary extinction. These two day-to-day effects, 'warming-up' and spontaneous recovery, are possibly the determinants of the form of the curve of the latent period (Fig. 4) on the first cycle. If a certain amount of inhibition of reinforcement (9) is accumulated on the primary acquisition trials, and if spontaneous re-

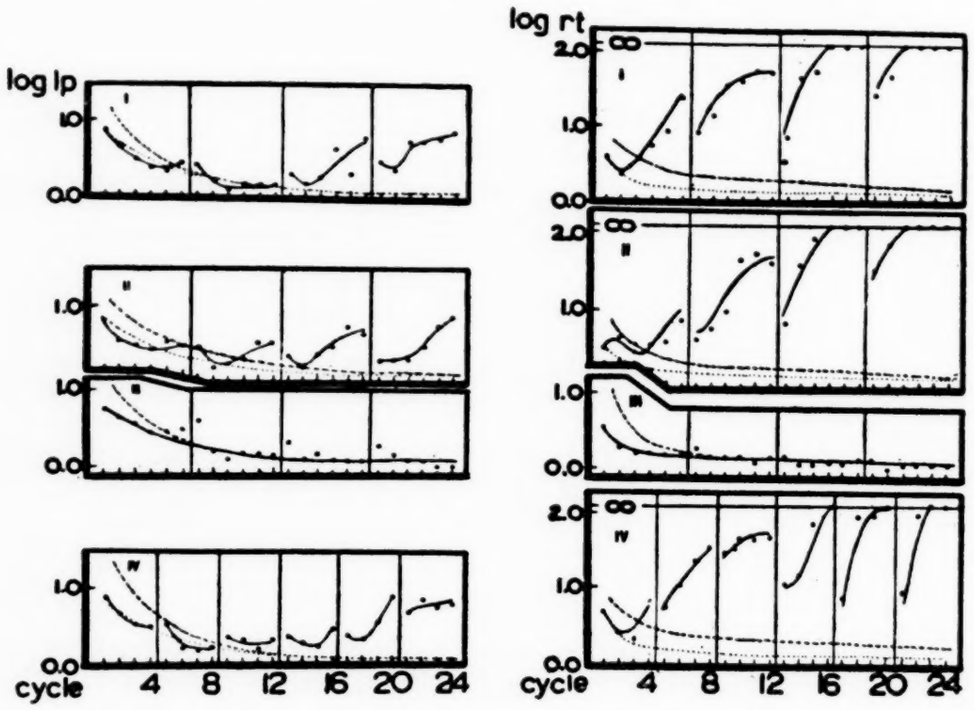

FIG. 6. Magnitude of the response to the negative stimuli (measured by the median of all unreinforced trials on each cycle), as a function of the number of non-reinforcements. The vertical lines on each graph separate the daily runs. Where "infinite" values have occurred, they are plotted on a horizontal line originating above 2.0 log units, and marked with the sign for infinity.

Log Latent Period: Each graph has the following smoothed curves:
1. Solid line: curve fitted to present data of group represented.
2. Dashed line: acquisition curve of each group.
3. Dotted line: curve fitted to present data, Group III.

Log Running Time:
1. Solid line: curve fitted to present data of group represented.
2. Dashed line: acquisition curve of each group.
3. Dotted line: curve fitted to present data, Group III.

covery takes place over night, a combination of this recovery with 'warming-up' might produce the curve which is obtained.

a. Log Latent Period:

The data of Group III reveal no tendency toward the development of a temporal discrimination. In the absence of discriminative stimuli, each reinforcement produces so great an increment in strength that the response is maintained at a level stronger than before through

three successive non-reinforced trials. Consequently, the two fitted curves draw regularly together, and from the end of the first day there is no recognizable effect of any single reinforcement or non-reinforcement on the succeeding trials. The change in strength over the course of the remainder of the experiment is gradual, and is not reflected especially in either positive or negative trials.

Through the first 14 cycles, the behavior of Group I is indistinguishable from that of Group III. There is no evidence of discrimination until the 15th cycle, when the process begins its progressive development, interrupted only by the 24-hour interval. Although the weakening of response to the negative stimulus follows cycle by cycle the negatively accelerated course typical of extinction, examination of the complete learning record reveals that within any cycle it is the first trial in which response to the negative shows the greatest decrement. From the first trial of the cycle on, the response becomes successively stronger so that by the third trial it is nearly as strong as on the succeeding trial. These two phenomena are met with in all three groups to which discriminative stimuli were presented. The finding in the latent period measurements that discrimination first appeared on the trial following reinforcement was unexpected. Occasionally the latent period on such a trial was observed to be artificially lengthened because the rat was still eating food which it had hoarded intraorally, but this was an infrequent occurrence. It is not responsible for the form which the development of discrimination has taken. The effect is genuine, and bears strong resemblance to the phenomenon which Pavlov (**12**) has termed 'induction.'

Despite the fact that the acquisition curve of Group IV is generally higher than that of I and III, the curve of strength of the response to the negative stimulus through the ninth cycle is essentially the same as those of I and III. Discrimination then appears to a slight degree for four cycles, the negative trials of each cycle taking the form of very low extinction curves; in the fifteenth cycle, discrimination begins to appear as it did in the case of Group I, and develops in the same manner.

The data of Group II are complicated by the relatively great daily deviations. However, when these are taken into account, the results are not dissimilar to those of the other groups. Where the acquisition curve of this group was higher than that of the others, the curve of median response per cycle to the negative stimulus seems to be slightly lower, although the day-to-day deviations make any determination of its exact form extremely unreliable. Whatever the exact form of this curve may be, examination of the complete learning record reveals that the strengths of response on the positive and negative trials of

each cycle are not equal until the eleventh cycle. During the next three cycles, response is approximately equally great in response to both positive and negative stimuli. On the 14th cycle, just as in Groups I and IV, discrimination clearly begins, and follows the same course of development.

b. Log Running Time:

The behavior of the running time measure of Group III parallels that of the corresponding latent period. The curves of response magnitude on both positive and negative trials draw regularly together over the course of a few cycles, even though they begin farther apart than do those describing the data on latent period. The complete learning curves also exhibit the same characteristic form: a series of extinction curves progressively diminishing in height until there are observable no differences between responses on the positive and negative trials. These findings parallel those of Skinner (**14**) on periodic reconditioning.

The running time data of Groups I, II, and IV are strikingly different from those of the latent period. First, discrimination appears to some extent on the first cycle, and rapidly increases in degree; there is no period of complete generalization of reinforcement before discrimination develops. Second, the responses on the negative trials of each cycle characteristically take the form of an extinction curve, and the curves of each successive cycle are displaced upwards from that of the preceding cycle. The present curves indicate the level at which these successive extinction curves occur, and consequently indicate the degree to which discrimination has developed; they reflect further the degree of spontaneous recovery occurring over the 24-hour intervals.

Groups I and IV behave alike in that both show on the unreinforced trials of the second and possibly of the third cycle a general level of performance strikingly similar to that of Group III. However, there is less discrepancy between the acquisition and extinction curves of these groups than there is between those of Group III. This is indicative of a lesser degree of generalization of reinforcement, and certainly reflects the difference of degree of decrement in response to the positive stimulus exhibited in the first cycle. A great difference in the strength of the negative and positive response develops progressively day by day after this initial strengthening of response on the negative trials. The trend is interrupted by daily spontaneous recovery. Significantly, the degree of spontaneous recovery exhibited by Group IV does not decrease progressively as does that of Group I; this would seem to be the only effect produced by the lesser degree of massing of extinction trials in Group IV.

Group II shows less generalization of the effects of reinforcement after the first reinforcement, so that on the second, third, and possibly the fourth cycle, the level of response to the negative stimulus is approximately equal to that to the positive. Subsequently, discrimination proceeds as it does in the other groups.

5. *The Effect of Reinforcement of the Positive Stimulus on the Strength of the Response to the Negative.*

The reciprocal effects of reinforcement and non-reinforcement of one reflex on the strength of the other are definite enough. Although the generalization of the effects of non-reinforcement is more clearly marked than the generalization of reinforcement, the latter is readily detectable in the differences between the various curves which have been presented.

To reveal any systematic changes in the increments in the strength of a response immediately after reinforcement of response to the same or to the other stimulus, the data on odd-numbered trials of discrimination learning have been plotted. Lines drawn between trials preceding and following reinforcement graphically demonstrate the effects of each reinforcement. These graphs are presented in Fig. 7.

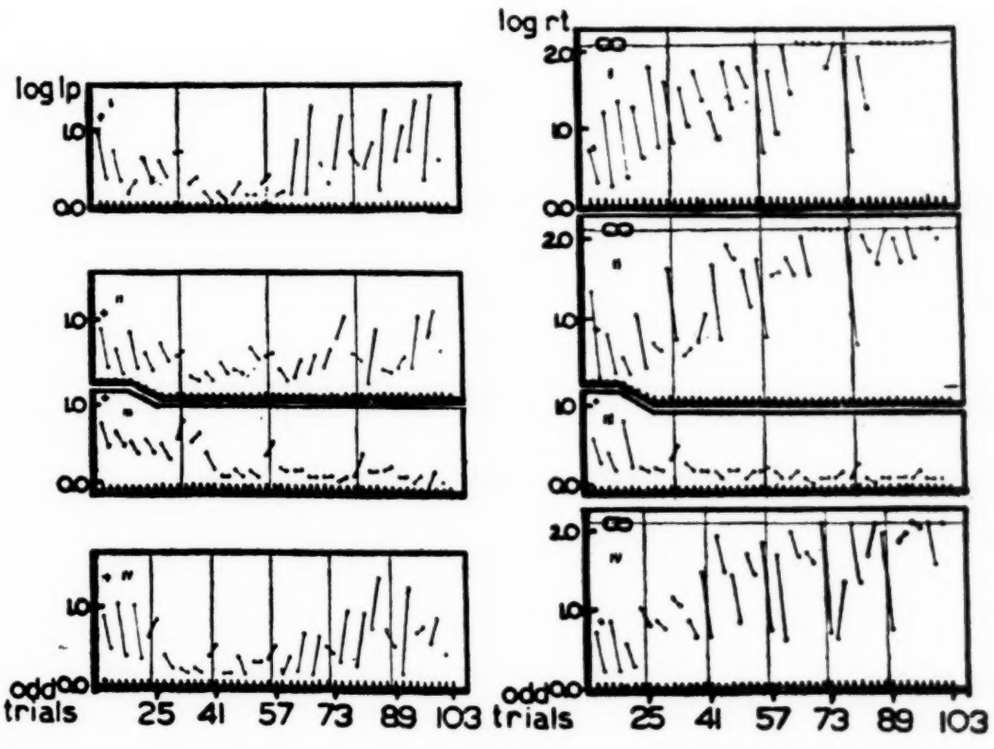

FIG. 7. The effect of reinforcement on the following run. Odd numbered trials are diagrammatically plotted, and lines have been drawn between the points representing trials immediately preceding and following reinforcement. Daily runs are separated by vertical lines. The crosses indicate the strength of the first response to the reinforced stimulus during the discrimination procedure.

Inspection indicates that although the variability of the effect is too great to permit any more precise presentation, there is sufficient regularity to indicate certain general trends. The coordinates of the starting point of each line are indicative of the strength of the response before reinforcement; the slope of each line varies with the amount of the increment in strength resulting from the intervening reinforcement. The 'induction' effect is clearly marked in the log latent period plots for all groups.

6. *Retention.*

It was possible to test a limited number of animals in each group for retention. After a varying interval from the last day of discrimination training, each animal was run for two cycles. The data on Groups I and IV were made available by Mr. R. N. Berry, who obtained them in the course of experimentation on certain of the animals used in the present experiment. Three animals of Group I were run, all on the twenty-first day after the end of discrimination learning. Three of the nine animals of Group II were run on the twentieth, five on the twenty-first, and one on the twenty-second day. The four animals of Group III were run as follows: one on the tenth, two on the fifteenth, and one on the twentieth day. Two of the members of Group IV were run on the twenty-first day, and one on the twenty-ninth. Since there were evident no differences which could be attributed to differences in the intervals, the records of all rats in each group have been lumped together. The median measures for each trial are presented in Tables I*A* and I*B*. Three rats, two in Group II and one in Group III failed to leave the starting box, and are not included.

TABLE I

RETENTION OF DISCRIMINATION

As Measured by the Median

Trial	A Log Latent Period				B Log Running Time			
	Group I	Group II	Group III	Group IV	Group I	Group II	Group III	Group IV
105	0.78	1.05	0.51	1.03	0.91	0.86	0.64	1.10
106	0.60	0.73	0.08	0.87	∞	∞	0.07	1.27
107	0.64	0.64	0.04	0.80	1.21	∞	0.07	∞
108	0.30	0.15	0.08	0.00	0.30	0.20	0.07	0.26
109	0.73	1.04	0.28	0.10	2.00	0.92	0.14	∞
110	0.72	0.64	−0.01	0.00	1.97	2.05	0.04	2.03
111	0.66	0.20	0.00	0.66	1.94	1.95	0.08	∞
112	0.08	0.15	−0.05	0.00	0.20	0.15	0.00	0.26

The discrimination shows little impairment over the intervals used. It should be observed, however, that a great degree of recovery from extinction has occurred, and that the effect of generalization of reinforcement is concurrently augmented. This great degree of retention is more familiar in conditioning experiments than in the usual 'rewarded' learning situation.

7. *Individual Differences.*

Certain individual differences appeared in the course of discrimination learning. None of these was such as to impair the description of the course of such learning which has been offered. The first of these differences which should be noted is in the rate of development of the discrimination. The latent period data of some animals clearly showed differential behavior long before it was evidenced in the group curves; in other animals, it was delayed for several cycles. Similarly, discrimination in the response measured by running time was in some rapidly developed, and in others slowly. In the latter case, a degree of generalization like that appearing in the latent period data occurred. One strikingly 'slow' animal showed no discrimination in the latent period until the twenty-first cycle, and in running time, until the fourteenth.

It was also observable that some curves, although they showed the changes characteristic of the group curves, were displaced upward one to two tenths of a log unit. These rats, then, ran uniformly more slowly.

Rarely, there appeared a deviation of which no account can be given. All runs of a given rat on a single cycle have in a few cases been displaced upwards as much as a log unit, but the form of the resulting curve was not different from that of the preceding and following cycles.

8. *Observational Material.*

During the course of extinction of the response whose strength was measured by the running time, certain forms of behavior appeared which were remarkably consistent from rat to rat.

The first of these appeared typically during that part of learning when the latent period indicated that complete generalization of reinforcement to both positive and negative stimuli had occurred. It can best be described as 'putting on the brakes.' As soon as the starting door was opened, the animal ran out at a considerable speed. As it proceeded down the alley, it slowed down rapidly in a manner which indicated active suppression of the running behavior; the animal, as it were, stopped itself. After some hesitation, it would then proceed slowly to the food box, or return to the starting box.

The second has been termed 'abortive entrance': the animal, actively exploring the region of the food box, ran into the food box, at the same time turning in such a manner that no sooner were its rear quarters in the box than its head appeared from inside. When the movement was complete, the animal usually remained sitting for a short time and then resumed its exploratory activity. Such 'abortive entrance' occasionally occurred several times during one trial. The third form of behavior observed was a marked increase in exploratory behavior. The animal moved from place to place up and down the alley, vigorously vibrating its vibrissae, moving its head, and leaning far off the alley. The regions in which exploratory behavior occurred most extensively were in the immediate vicinity of the food box and in and about the starting box. Many animals would attempt to clamber up the screens, and occasionally one would climb down on the rubber roller and support which maintained the runway in position. When this occurred, the animal was immediately replaced on the alley. Interpolated between such exploratory behavior was running back and forth on the alley. Some animals ran up and down the alley as many as six times in the course of two minutes.

These phenomena are very similar to those reported by Wendt (**15**) in his investigation of loudness discrimination in monkeys. However, in his experiment, such activity occurred between the presentation of the signalling stimulus and that of the conditioned stimulus. Wendt considered that his animals might have been expected to show indications of Pavlovian 'inhibition of delay' during this interval.

Only once was there observed behavior symptomatic of inhibition as it was conceived by Pavlov. Even on those trials when the animals were developing discrimination in the reflex measured by the latent period, they were actively exploring the starting box and the door region. 'Huddling,' such as that reported by Gagné (**6**) and others did not appear.

When the door of the food box was closed, it invariably rested on the tail of the animal. On unreinforced trials the tail was withdrawn by the animal almost immediately. But occurrence of the reinforcing reflex clearly seemed to inhibit such withdrawal. During the course of discrimination training, observations were made on this. At one minute after closure of the door to the food box, on 1004 of a total of 1104 reinforced trials, the tail was not withdrawn. Corresponding data on trials where reinforcement was absent yield a frequency of 21 out of 3312 possible.

Defecation and urination *never* occurred on a reinforced trial. This also seems to suggest inhibition of conflicting responses by eating behavior. Their occurrence on non-reinforced trials, however, was not so frequent as to suggest an emotional effect of non-reinforcement.

Discussion

According to the present analysis, the two habits manifested in the behavior which has been studied constitute two chains composed of two reflexes each. Skinner (**13**, **14**) has defined the reflex as 'the correlation of a stimulus and a response at a level of restriction marked by the orderliness of changes in the correlation.' By this definition, the analysis of the behavior into at least two, and possibly four, reflexes is correct, and only the applicability of the concept of chaining is open to question. If this concept is rejected, then it would seem to follow that in measuring both latent period and running time, two different measures of the same reflex have been made. But the striking differences in the behavior of these two measures following the same procedure of reinforcement and non-reinforcement render this highly improbable so that it may be concluded that four, and not two, reflexes have been investigated, and that these reflexes are organized into two chains. This investigation, then, has determined the course of the changes in the strength of the members of the two chains occurring as a consequence of differential reinforcement of the chains. Such changes have been revealed as orderly and gradual. They are not independent of one another; a major degree of interaction occurs.

Discrimination develops in those reflexes immediately preceding the reinforcing reflex as the simultaneous strengthening of one and extinction of the other. This statement is qualified only by the extent of the changes in the strength of one induced by reinforcement or non-reinforcement of the other. Its course conforms with that described by Hilgard, Campbell, and Sears (**8**), and by Skinner (**14**).

The development of discrimination in reflexes more 'distant' from reinforcement cannot be so simply described. Initially the unreinforced reflex shows induced changes in strength equal to the direct changes in strength resulting from periodic reinforcement. This is comparable to the great degree of 'generalization of excitation' reported by Pavlov (**12**) as appearing in the trace conditioned reflex. The weakening of the reinforced reflex which eventually appears follows a course suggestive of what Pavlov has termed 'negative induction.' 'Induction' is one of the few findings of Pavlov which have received only limited attention. It has played no part in the construction of conditioned reflex theories of learning. Although tentative hypotheses may be advanced with respect to this phenomenon, a need for critical research is indicated. When non-reinforcement is considered as simple failure of occurrence of the reinforcing reflex without regard to the previous occurrence or non-occurrence of the reflex being extinguished, this finding cannot be considered as a correlate of the interval between the presentation of the stimulus and

the non-reinforcement of response to it. It is proposed that the consequences of variation of the interval between reinforcement of one reflex and the presentation of the stimulus to another, which has not been reinforced, be investigated.

The data which have been presented bear close resemblance in detail to comparable data obtained in the classical differential conditioning experiments of Pavlov (**12**). In both cases, trial-by-trial measure of response in individual animals clearly shows the phenomena which Pavlov described; here, the results are shown to occur in group as well as in individual data. The phenomena which have been reproduced are those from which Pavlov derived many of the concepts which he employed in the description of discrimination. These concepts include: 'generalization of excitation,' 'differential inhibition,' 'inhibitory after-effect,' and 'induction.' The foundation of his proposed measure of stability of differentiation is indicated. Other Pavlovian theoretical notions whose empirical basis has been verified are 'extinction,' 'inhibition,' and 'excitation.' The phenomena from which were inferred the properties of these processes have also been largely confirmed: spontaneous recovery ('lability of inhibition') and the effects of spacing on extinction, among others. In both sets of experiments, 'warm-up' and evidence of discrimination on the first closely successive presentation of positive and negative stimuli appeared. There is no evidence in the present experiment on 'external inhibition,' 'disinhibition,' and 'irradiation and concentration of excitation and inhibition.'

In one striking respect, Pavlov's account has been found inadequate. The behavior manifested during the extinction of the unreinforced reflexes bears little resemblance to that described by Pavlov, but it is rather suggestive of the formulation proposed by Guthrie (**7**) and Wendt (**15**). The great activity of our animals during extinction of response to the negative stimuli is in marked contrast to the general suppression of activity described by Pavlov as appearing during extinction and during the latent periods of delayed and trace reflexes.

The data presented by later experimenters (**9**) on the conditioned reflex which have led to the concept of 'inhibition of reinforcement' with subsequent spontaneous recovery seem to be substantiated by our data on the behavior of the latent period during the first days of experimentation.

Insofar as the present experiment has repeated the findings of Pavlov, it tends to confirm those theoretical treatments which have been based on his work. Indeed, the form of the curves presented seems to confirm in detail the hypotheses of Spence with respect to the magnitude of increments and decrements in reaction tendencies as a consequence of reinforcement and non-reinforcement. Since we have

used only two pairs of stimuli, no conclusion can be drawn with respect to the 'gradients of generalization.' However, the technique of the present experiment might well be used in the determination of the form of such gradients.

Summary

1. The present experiment has considered the acquisition of discrimination in a simple form of behavior. This behavior consists in running down a narrow runway to a food box when the door of a starting box is opened. Analysis of this habit indicates that it may be considered a chain of two reflexes. The measures of strength of these two reflexes which have been employed are termed respectively *latent period* and *running time*. The course of changes in strength of both reflexes in each of two such chains resulting from differential reinforcement of the chains has been traced. As a control, the effect of the periodic reinforcement of one chain has been determined.

2. The experimental design permits control of preliminary training, drive, amount of reinforcement, spacing and massing of trials, and magnitude of both positive and negative stimuli. The independent variable is the systematic association of reinforcement and non-reinforcement with responses to two stimuli, black alley and food box, and white alley and food box. The dependent variable is the strength of response to those stimuli.

3. The periodic reinforcement of a single chain produces initially a series of extinction curves between successive reinforcements. These become progressively lower. Ultimately the strength of response reaches a high and stable level unaffected by single reinforcements.

4. Differential reinforcement of two chains results in the gradual development of discrimination. The strength of response to the positive stimuli follows the course of a smooth acquisition curve. The strength of the second reflex in the unreinforced chain decreases following a course typical of extinction; the strength of the first initially increases with the strength of the reinforced chain before evidence of discrimination clearly appears.

5. The following phenomena, familiar from Pavlovian conditioning, have been observed: extinction, spontaneous recovery, generalization of the effects of reinforcement and non-reinforcement, and induction.

6. The behavior of the animals during extinction does not exhibit the symptoms of Pavlovian inhibition.

7. A decremental effect of massed practice is evident in the data. 'Warming-up' also appears.

8. The course of acquisition of discrimination in the locomotor response which has been studied conforms in detail with that described by Pavlov in the conditioned salivary reflex.

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FOURIER TRANSFORMS OF THE ELECTROENCEPHALOGRAM DURING SLEEP [1]

BY JOHN R. KNOTT, *University of Iowa,*

FREDERIC A. GIBBS, *Boston City Hospital,*

AND

CHARLES E. HENRY, *Western Reserve University*

Previous analyses of the EEG during sleep (**1**, **2**, **4**, **6**, **7**, **8**) have relied upon categorical descriptions of the record in terms of predominant types of electrical activity. Categorical descriptions of any phenomena mask the dimensionality of the data to which they are applied and may thus be somewhat incomplete, if not misleading. In the case of the EEG, categorizing masks the fact that the record is composed of a continuous series of frequencies and amplitudes. The current nomenclature applied to the EEG during sleep suggests that energy is released at certain modes of the frequency continuum rather than at others, while a system of analyses based on the assumption of continuous dimensions demonstrates that this is not literally true, but that more energy is released at certain points than at others.

The present investigation has attempted to analyze the EEG during sleep in terms of a bidimensional system—energy *vs.* frequency. In this manner a more accurate and complete picture of cortical activity under the condition studied is made available.

Apparatus and Procedure

The apparatus consisted of high-gain, low-frequency amplifiers which drove an electrodynamic oscillograph element recording on moving film to give a variable area shadowgraph. This record was then analyzed by means of the Grass low-frequency wave-analyzer (**3**). The resultant record was a plot of energy *vs.* frequency.

Records were made under two plans of experimental attack. In the first series, six subjects were studied during all-night sleep, the EEG's being recorded continuously on a multi-element ink-writing oscillograph. At irregular intervals 30–45 sec. runs of the film camera were made to record for analyses particularly clear exhibitions of the traditional categories of electrical activity during sleep (low voltage, spindles, spindles plus random). Monopolar leads from the left motor area were used. (This series was obtained by J.R.K. and C.E.H.)

In the second series, one subject was recorded during alternate 30-sec. intervals from retiring to awakening, all records being made on the camera. A monopolar left occipital lead was used. The subsequently obtained energy-frequency transforms were then photographed on moving

[1] This research was a joint project conducted at Boston City Hospital and at the University of Iowa. All records in *Part A* were secured in the laboratory of physiological psychology at the University of Iowa; all records in *Part B* were secured at Boston City Hospital. All analyses were made at Boston City Hospital.

picture film in consecutive order, in a manner analogous to that followed in the making of animated sketches. When viewed by projection, this analysis provided a three-dimensional picture of electrocortical phenomena during sleep: energy *vs.* frequency *vs.* time. This last method is dynamic, the former, static. (This analysis was devised and conducted by F.A.G.)

Results

A. Static Analysis.—The data secured in this section of the investigation indicate that the traditional classification of sleep rhythms of the EEG does not take into account all of the phenomena exhibited. Figs. 1, 2, 3, 4, 5, and 6 show the relative (percent) energy *vs.* frequency during the categorical activities of 'low voltage,' 'spindles' and 'spindles plus random' in each of the six subjects. It will be observed that a classification into any given type for all of the subjects, which would imply an identity of electrocortical activity, is not associated with identical energy *vs.* frequency characteristics. Within a given subject, it was also found that the same categorical type of activity did not serve as an index of identity of these characteristics.

It appears that the major differentiation of states of sleep and waking is characterized, in terms of the EEG, by differences in the distribution of energy in various portions of the frequency continuum. While waking states are associated with release of relatively little energy in the bands below three cycles, sleep is associated with relatively great energy in this area. To a lesser extent, while waking states are associated with release of relatively little energy in the 13–15 cycle bands, sleep is associated with release of relatively greater energy in this area. To a still lesser extent, while waking states are associated with relatively great energy in the 8–12 cycle bands, sleep is associated with relatively less energy in this area.

Fig. 7 indicates the extent to which these statements were found to be true. In these data, the percent energy between one and three cycles, between eight and twelve cycles, and between thirteen and sixteen cycles have been computed from the energy-frequency spectra of four subjects upon whom satisfactory pre-sleep records were available. These values have been plotted against the categorical type of record as determined by evaluation of the concomitantly recorded ink-writer records.

It will be seen that in all of these cases there was at one time or another more energy in the 1–3 cycle band (in categorical terms, 'random') during sleep than during waking. In three of these four cases this was true throughout practically all of the samples obtained.

The increment in the 13–16 cycle band is clear in three out of these four cases, while the other exhibits a decrement in energy in this band, even though, categorically, there were clear exhibitions of 'spindles.'

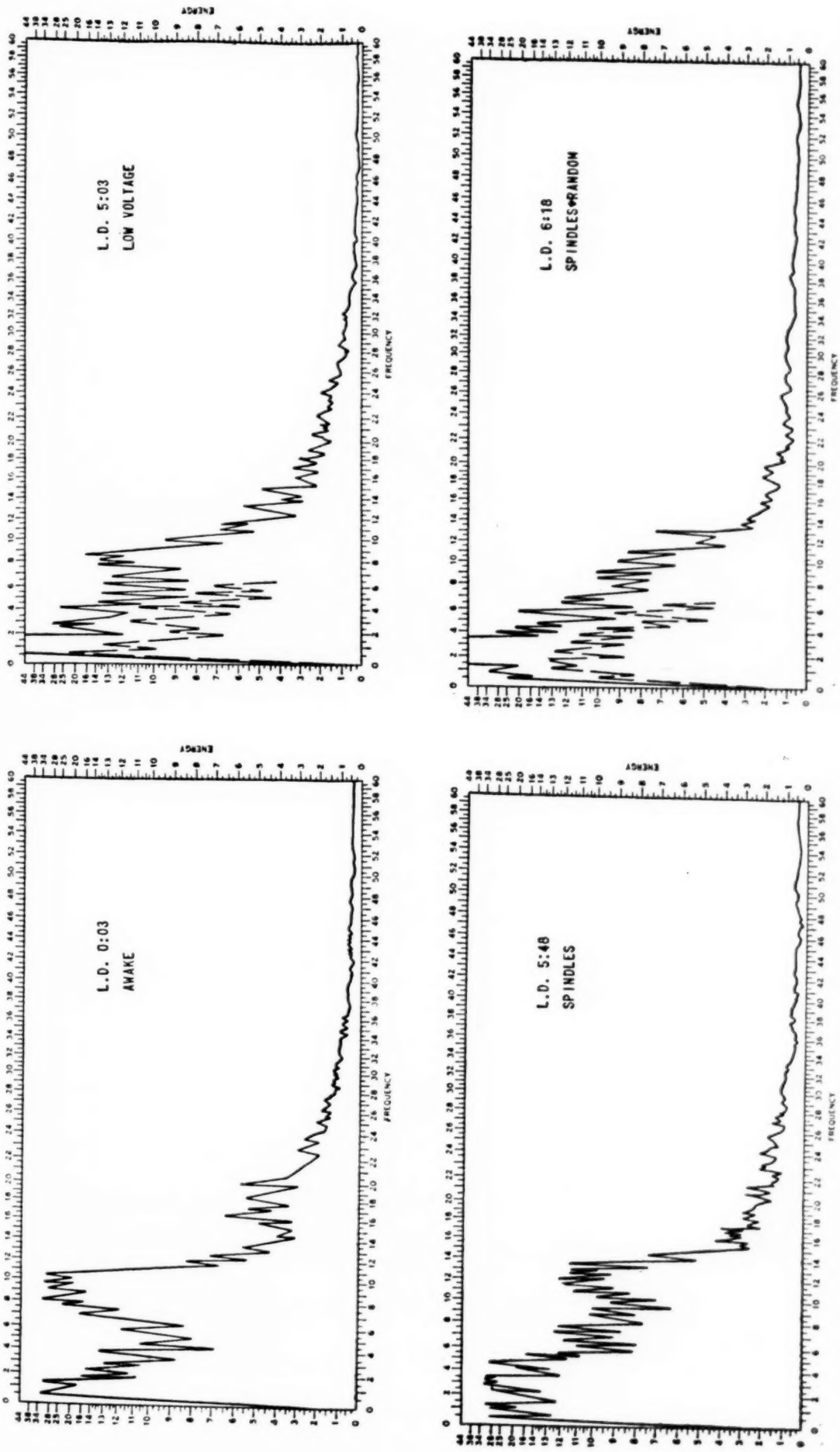


FIG. 1. Energy-frequency transforms of the electroencephalogram during waking and three 'stages' of sleep: 'Low voltage,' 'spindles,' 'spindles plus random.' The dashed line represents one-half the energy signified by the solid line.

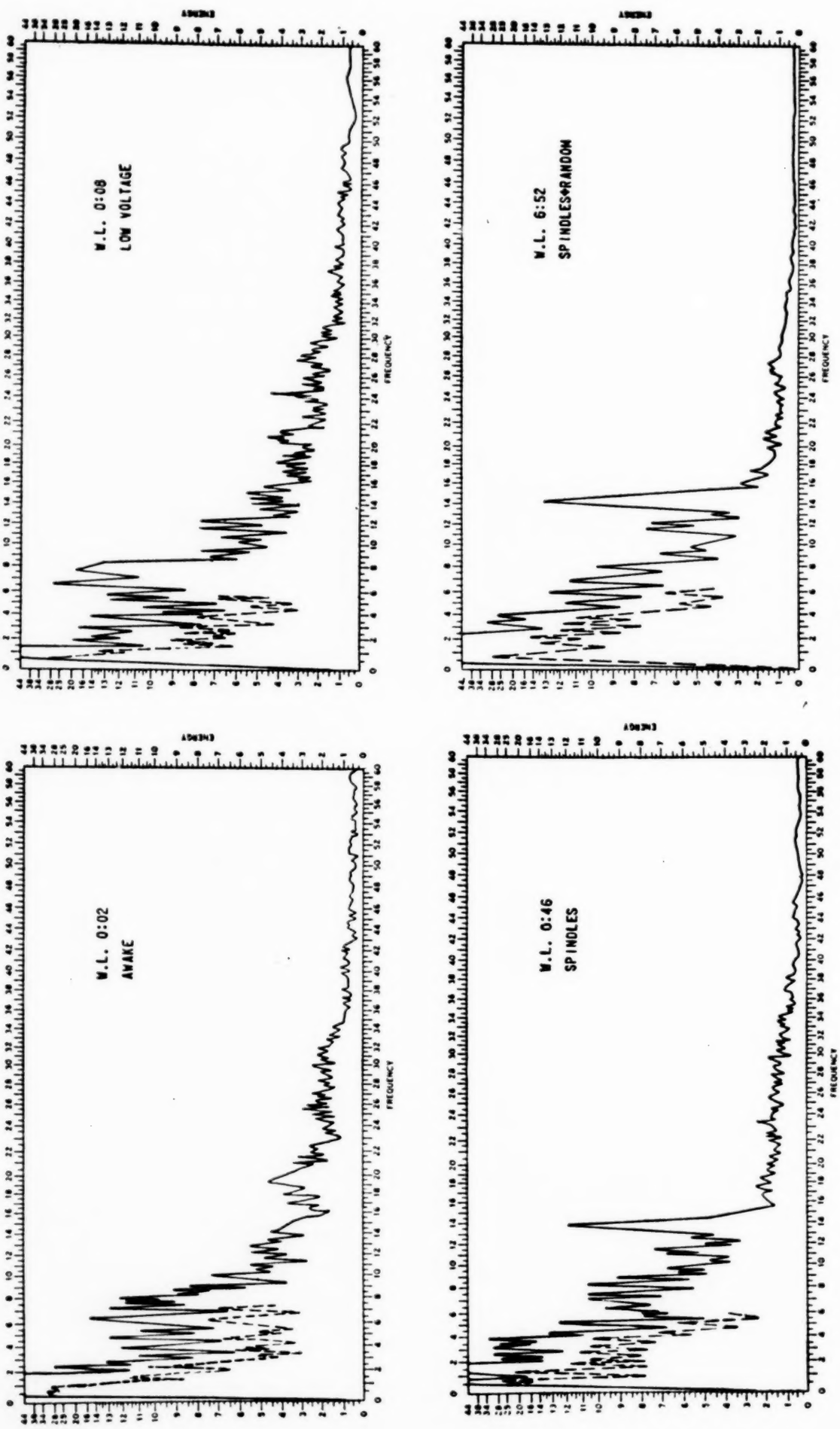
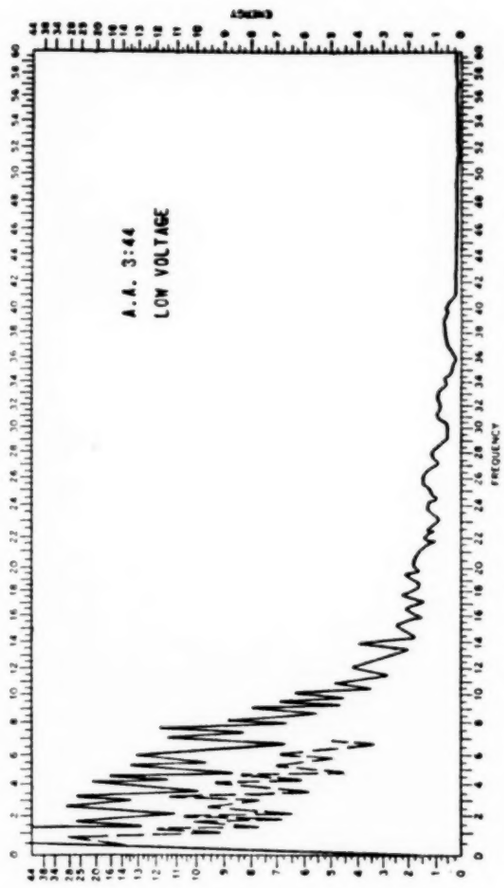
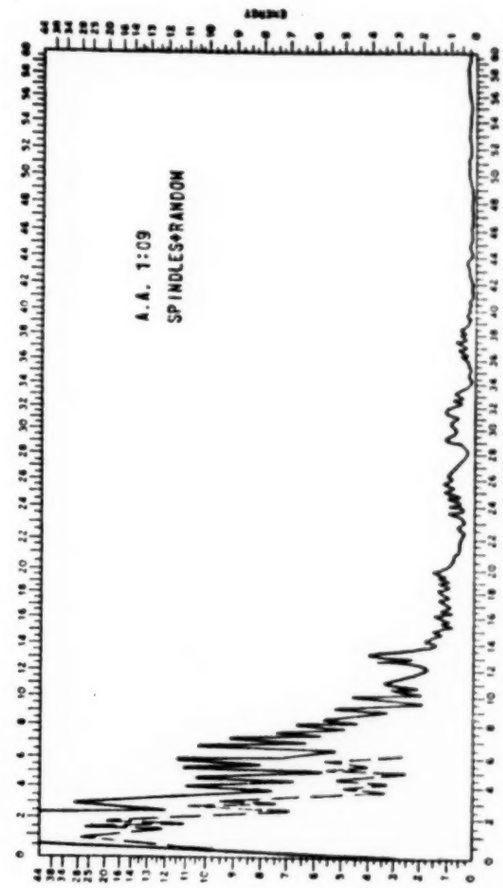
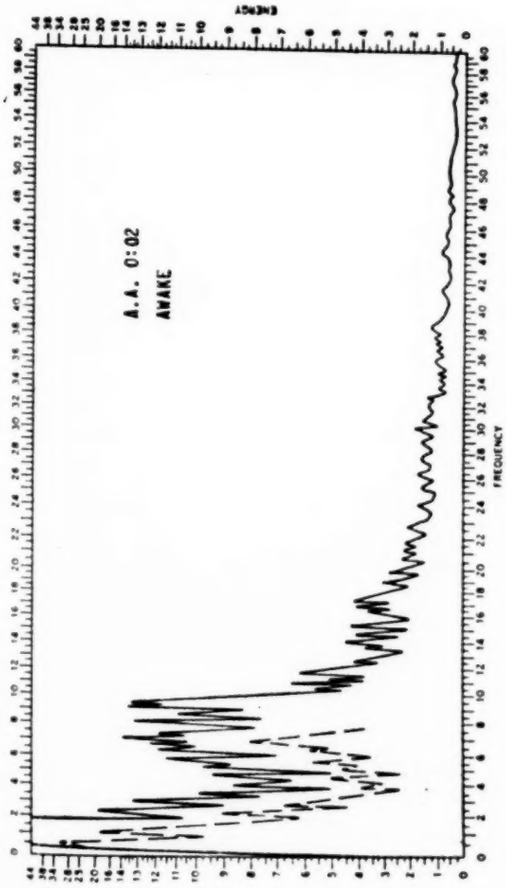


FIG. 2. For description see Fig. 1.







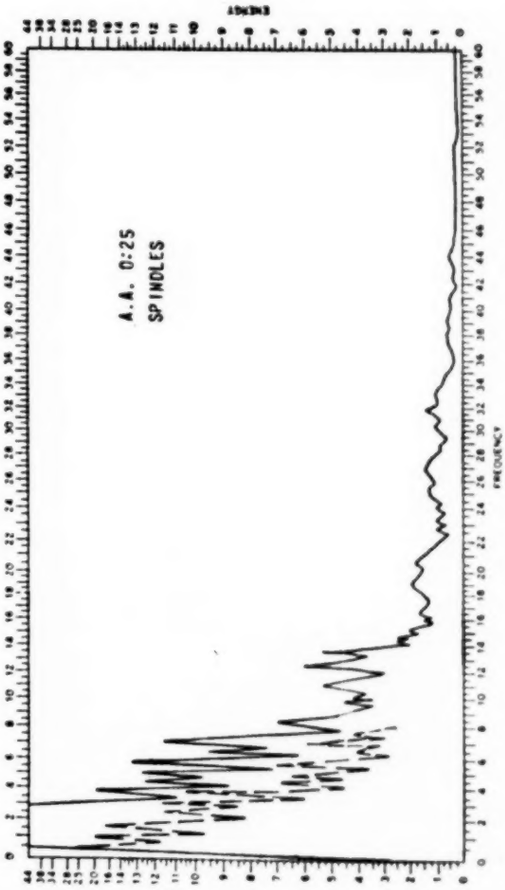


FIG. 3. For description see Fig. 1.

FIG. 2. For description see Fig. 1.

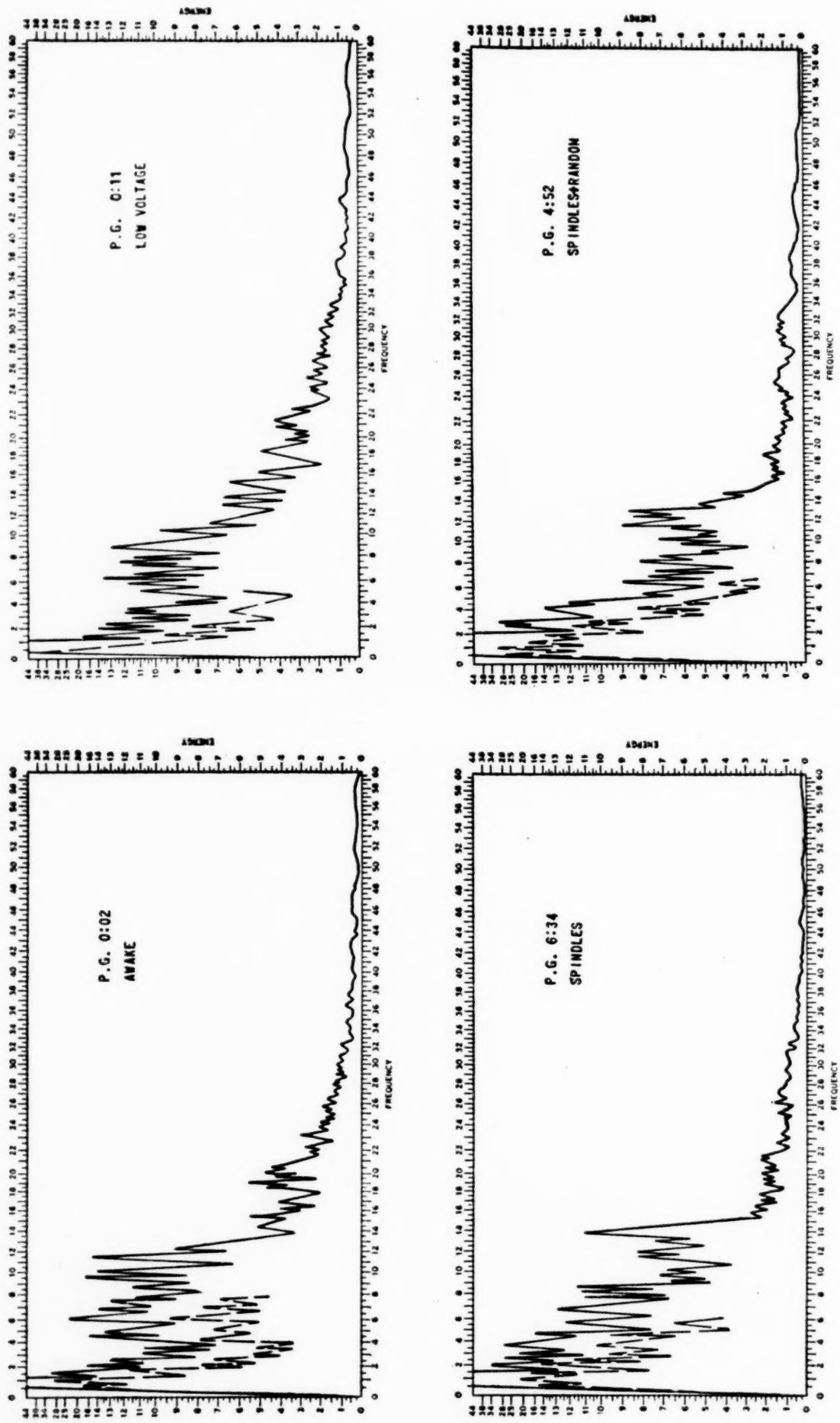


FIG. 4. For description see Fig. 1.

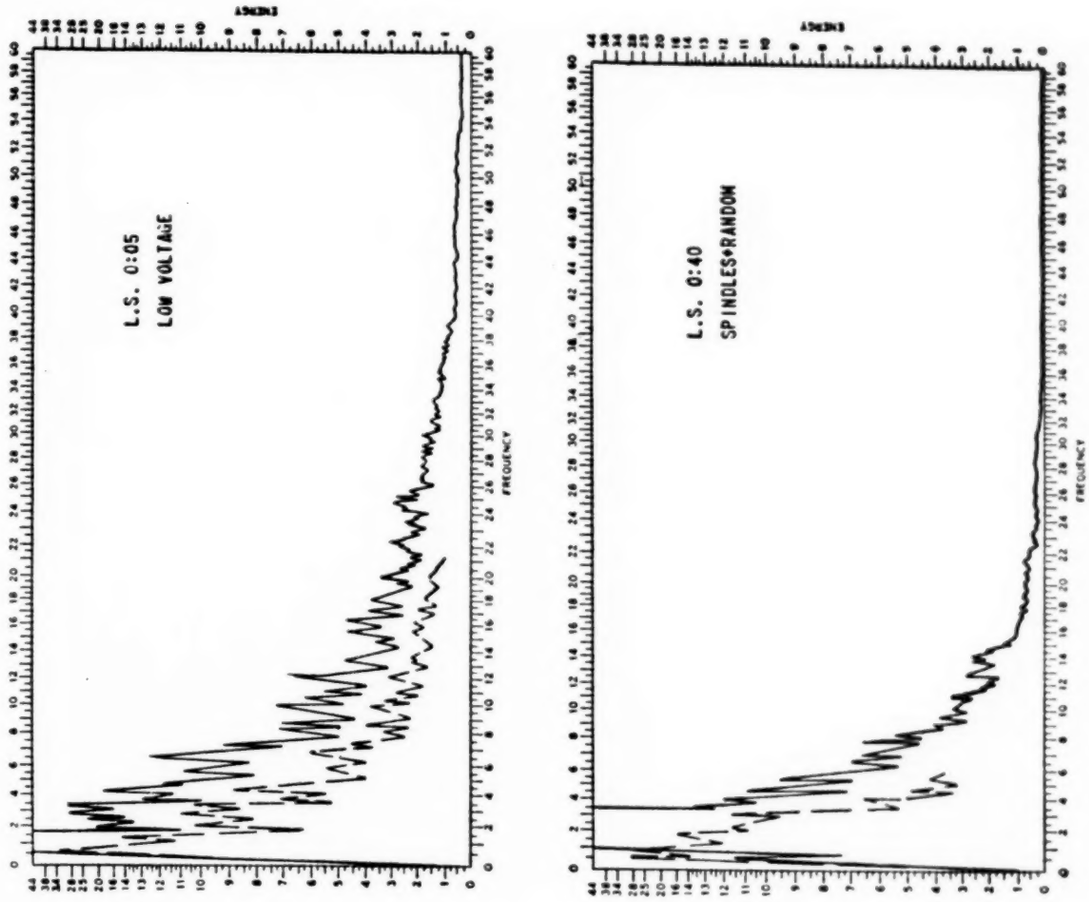


FIG. 5. For description see Fig. 1.

FIG. 4. For description see Fig. 1.

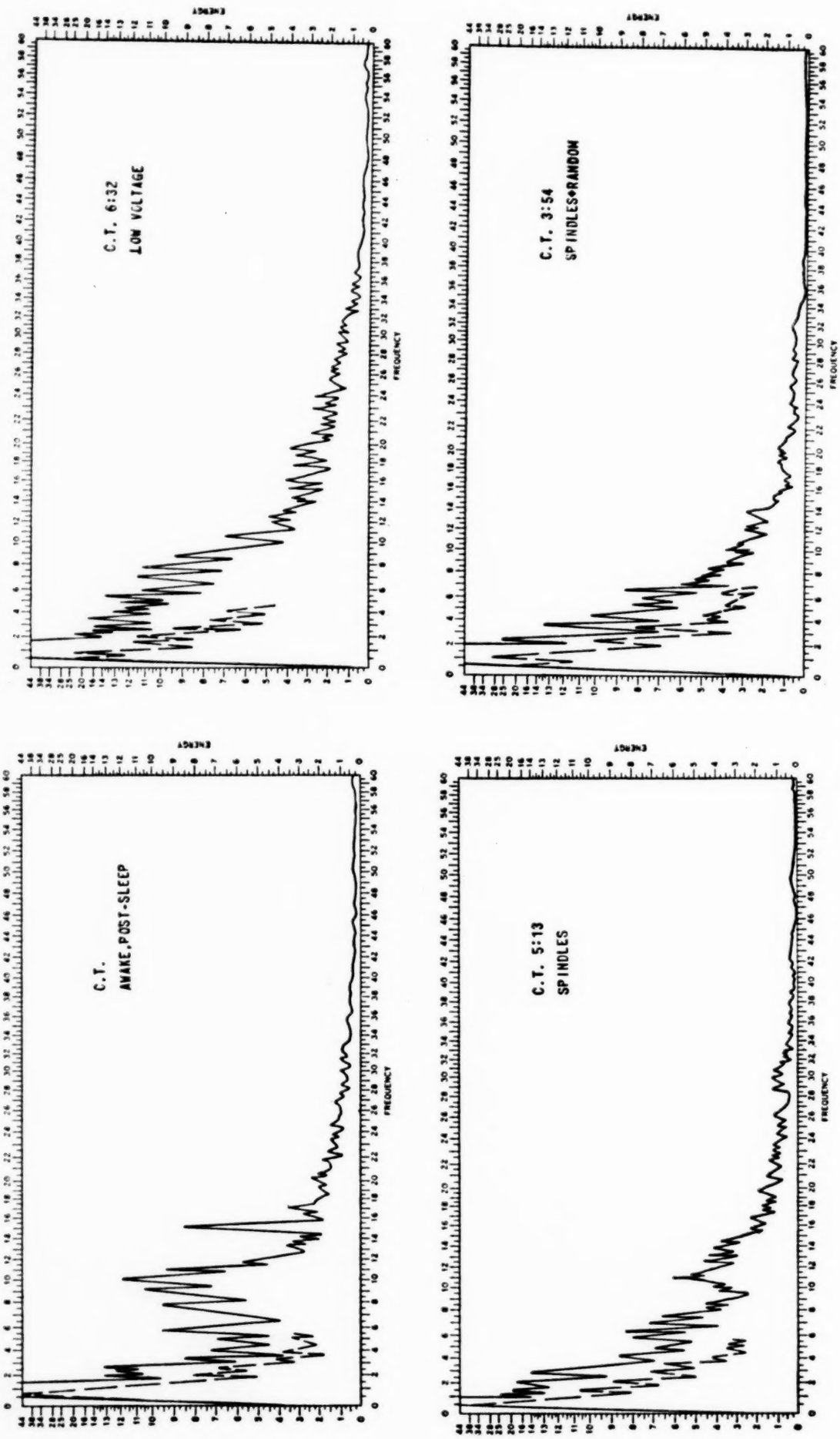


FIG. 6. For description see Fig. 1.

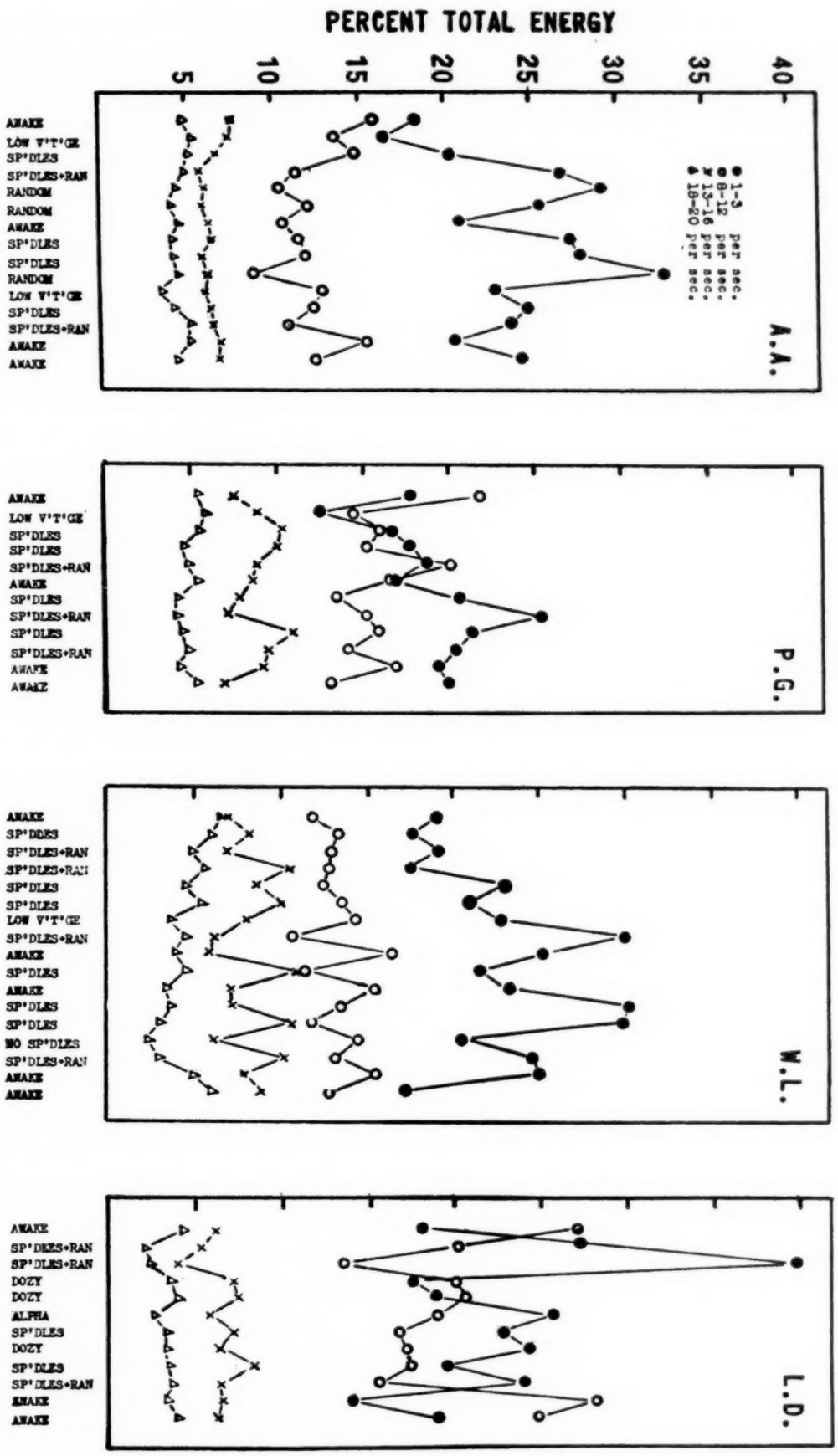


FIG. 7. Percent total energy in each of four bands (1–3; 8–12; 13–16; 18–20) during each recorded sample of EEG for the four subjects of Figs. 1, 2, 3, and 4. Each sample was categorically defined in terms of the ink-writer record. Inter-relationships among the bands are discussed in the text.

The 8–12 cycle bands exhibited less energy in sleep than during waking in three out of the four cases. This decrement was, in the cases in which it was exhibited, exceptionally clear.

The relationships between the percent energy released in these various bands can be determined from these data. It will be seen that, *in general*, as the energy increases in the 1–3 cycle bands, it decreases in the 8–12 cycle bands. *In general*, as the energy increases in the 13–16 cycle bands, it decreases in the 8–12 cycle bands. These generalizations do not hold for all cases, and there seems to be some variation within single cases.

In cases A.A., W.L. and L.D., the 8–12 : 1–3 relationship is essentially linear; in case P.G., it tends to be so; the other cases show little systematic variation. The 8–12 : 13–16 relationship is much less linear than the 8–12 : 1–3, although case W.L. tends to exhibit such a trend. The other cases are much more variable. It would appear fruitful to discover the factors responsible for this variability, since during some parts of the night the linearity and the trends are more apparent than at others.

B. Dynamic Analysis.—Certain general features of the EEG during sleep, as discovered by three-dimensional analysis, may be stated. Since this method includes the dimension of time, it contributes much to the study of variability of the relationships between the various bands. While there is a mutual verification by the static and dynamic analyses, the latter makes possible additional conclusions regarding the course of electrocortical events in sleep.

The high energy usually appearing in the 10 cycle band during waking initially oscillates along the frequency continuum during the early stages of drowsiness. The limits of this oscillation were observed to be between 11 and slightly less than 10 cycles. While the energy at 11 became less, the energy at the 9.5 point greatly increased in magnitude, the 11 cycle peak finally disappearing. In the meanwhile, the energy at one cycle greatly increased, while a mode of energy at 19 cycles became less. Soon after the disappearance of the 19 cycle peak, a new peak appeared at 17 cycles, with subsequent shift along the continuum between 17 and 18, then 18 and 16, and a final apparent stabilization at 15 cycles, at which point the energy increased greatly. The energy peak formerly falling at 9–9.5 now had become reduced in energy, apparently joining the 1–3 cycle bands.

This process was neither strictly progressive nor irreversible. Several times, before the 9–10 cycle peak disappeared, and before the disappearance of the 15–19 cycle peak, the process reversed as the subject roused slightly, as with a cough. Since the bodily disturbance usually preceded the shift in the energy *vs.* frequency

distribution toward faster bands, it is reasonable to suppose that in these instances stimulation from the viscera and lower centers caused the shift in electrocortical pattern.

After a period of from two to three hours of sleep, the total (absolute) energy in the spectrum decreased, with no pronounced energy peaks in any of the bands above three cycles. Small energy peaks were observed to be transient in the 12–14 cycle band. It will be recalled that the energy originally exhibited as a peak at 19 cycles moved to slower frequencies, having been last observed at 14 cycles. Energy now being released at 12 cycles may presumably be the resultant action of elements formerly producing faster frequencies.

One of us (C.E.H.), in a serial analysis of continuous ink-writer records of 20 subjects during sleep, has observed that what goes under the categorical definition of 'spindles' (a phenomenon appearing at approximately 14 cycles) first appears at frequencies of 14–15 per sec., with a subsequent decrement in frequency to as low as 11–12 per sec. These slowest 'spindle' frequencies presumably appear during the deepest stages of sleep. Since these limits have impinged upon the defined limits of 'alpha' (8–12 cycles), there is a very real possibility that certain inconsistencies in the relationships between bands which were found in the static analysis are due to this overlap. This serves as an excellent illustration of the dangers of categorizing in a rigid manner, rather than measuring in terms of a continuum. Without the dynamic method of analysis, this factor would probably have not been so easily discovered.

Discussion

The observations based on both the static and the dynamic analyses lead to two explanations of the phenomena. According to the first of these, there is a shift in the rate of beat of certain cortical elements, the general rule being that there is a slowing of their rate of discharge. Thus the 12–14 cycle 'spindles' may be thought of as being produced by elements which produce 18–20 cycle activity in the waking record (as suggested by Jasper and Andrews, **5**). Likewise, the 1–3 cycle 'random' waves of sleep may be thought of as being generated by elements producing the 8–12 cycle 'alpha' rhythm in the waking record.

The most adequately demonstrated relationship is that between the 8–12 and the 1–3 cycle activity; although the dynamic analysis indicated such a relationship between the 18–20 and the 12–14 cycle rhythms, the static analysis did not reveal such a trend, due, it is believed, to inadequacies inherent in that method of analysis.

The relationship between the 1–3 and the 8–12 cycle band which is so apparent in certain cases might lead to the supposition that the relative amount of alpha (8–12) activity limits the amount of random (1–3) activity which can be made manifest. This is not the case. It has been elsewhere demonstrated (**4**) that there is no relationship between the amount of random activity in sleep and the amount of alpha activity in the waking state, and it has been shown (**6**) that there is a great deal of similarity between dominant and rare alpha individuals during sleep. Thus, it would appear that there are mechanisms capable of producing alpha during waking (and which do produce random during sleep) which are prevented from doing so. The question of the differences between dominant and rare alpha subjects is thus not a question of the presence or absence of a particular mechanism, but of the degree to which it functions and the factors conditioning this degree.

A second interpretation of the data would suggest that sleep is a condition causally represented by the activity of certain bioelectric generators. These might be predominantly slow. As sleep progresses they would be expected to drive other generators, to a greater and greater degree, at their own rate. Alpha generators would thus be slowed, not by processes inherent within themselves, but by a spread of 1–3 cycle activity. It would be necessary, in order to make this interpretation consistent, to postulate a second generator which is causally characteristic of sleep, a 14 cycle generator. Since activity in this band seems to be present practically continuously throughout sleep, as one of us has observed (C.E.H., unpublished), appearing in high-gain, tuned filters from the earliest stages of sleep until awakening, this might be a very real possibility. A great deal more investigative work on this problem is needed before any durable conclusions can be reached. Rather than choose one horn of an either-or proposition, it would be best to admit both possible interpretations and attempt to discover the relative importance of each in the determination of the EEG in sleep.

Summary

1. Fourier transforms of the EEG during sleep have been obtained and subjected to two methods of analysis, one static, the other dynamic.

2. The static method of analysis indicates that the traditional categories of sleep do not take into account all of the phenomena appearing on the record. During sleep, as during the waking state, there is a continuous distribution of frequencies. Electrocortically, sleep differs from the waking state solely in the distribution of energy throughout the continuum of frequencies, not in the introduction of

new frequencies: during sleep there is an increase in energy in the 1–3 cycle and the 13–16 cycle bands, and a decrease in the 8–12 cycle bands. There appears to be a negative relationship between the activity of the 1–3 and the 8–12 cycle bands—as the former increases in energy during sleep, the latter decreases.

3. The dynamic method of analysis indicates that there is a progressive shift downward in the energy peaks along the frequency continuum, the slowest frequencies apparently being contributed to by the medium frequencies, and the 13–16 cycle band being contributed to by the faster 18–20 cycle bands.

4. It is assumed that two interpretations may be made of these data, one that there is a shift in the rate of discharge of generators composing the EEG, the other that the condition of sleep is a condition characterized by dominant activity of generators acting in the 1–3 cycle band and in the 13–16 cycle band. The first interpretation seems to be more adequately demonstrated by the data obtained in the present study, but the possibility remains that a complete account of the phenomena will include both interpretations.

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THE ROLE OF THE OPTIC CORTEX IN THE DOG IN THE DETERMINATION OF THE FUNCTIONAL PROPERTIES OF CONDITIONED REACTIONS TO LIGHT

BY KEMPTON G. WING AND KARL U. SMITH

The University of Rochester

A. Introduction

The experiment reported here constitutes a part of a general investigation now being conducted concerning the functional role of the cortex in defining some of the main dynamic properties of learned reactions. The present study is designed specifically to examine the functional value of the visual areas of the cortex in the retention and extinction of a conditioned response to light, and in the generalization and second-order elaboration of this particular response.

Present theories of the physiology of memory and of the neural basis of learning have their empirical derivation, in part, from the findings related to the retention and learning of visual habits after lesions in the cerebral cortex (**2**). The fact that a brightness discrimination habit, established through reward learning, is abolished by bilateral destruction of the visual areas of the cortex and can be reëstablished only through postoperative training (**3**, **4**, **8**) has been emphasized particularly by those who believe that the cortex plays a major or primary role in the determination of vision and the retention of visual habits in the normal animal. The question has existed for some time, however, whether all learned visual habits are equally dependent upon the striate areas of the cortex for their retention. Specifically, there is some doubt that reactions to brightness differences of a sort simpler than those involved in the brightness discrimination habit are mediated by the cerebral cortex. The investigations of Marquis and Hilgard (**5**, **6**) especially have suggested this problem, for their observations show that conditioned lid-closure to light in dogs and monkeys displays at least partial retention following destruction of the visual cortex.

The lack of uniformity of the results for brightness discrimination and the conditioned lid-closure makes it seem desirable to analyze, from the standpoint of the theories of both learning and vision, the essential differences between the functional value of the cortex in brightness discrimination and in other types of learned responses to

differences in light intensity. In the present investigation, we have selected for observation a conditioned avoidance reaction of the hind leg in the dog, in the attempt to ascertain whether or not somatic conditioned motor reactions of a more general character than lid-closure are specifically dependent on the optic cortex for their retention. In addition to providing information about the retention of conditioned reactions to light, the experiment permitted investigation of important related questions of extinction, generalization, and second-order elaboration of the conditioned response and of the dependence of these dynamic properties on the visual cortex.

B. Method

Fig. 1 is a diagram of the apparatus. The dog is placed on the stand and held in position by a harness attached to adjustable rods. The left hind leg is strapped to the floor of the stand,

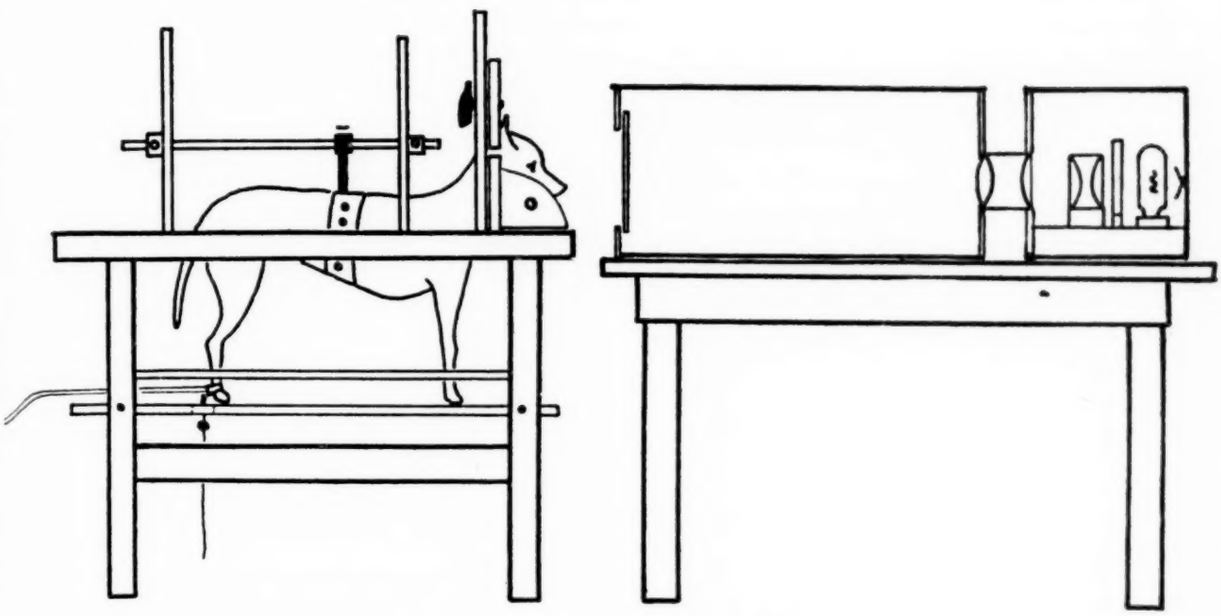

Fig. 1. Diagram of the apparatus.

and electrodes are clamped around the instep of the right leg. A wooden stock is used to hold the animal's head in a position about 18 inches in front of a milk-glass panel, 8 inches wide by 10 inches long, through which light is projected. Movement of the animal is further restricted by vertical quadrants of wood at either side of the head. The light panel and projection apparatus are located on a separate table in front of the dog. A 500-watt bulb is used as the light source for illuminating the milk-glass panel. Except for the lens aperture, the projection box containing the lamp is enclosed in sound-proofing material in order to prevent the click of the lamp, as it is turned on, from serving as an extraneous cue for the animal. The unconditioned stimulus, an electric shock, is supplied by a variable current shocker. The shock is keyed through the output circuit, which is arranged in series with the leg electrodes. In second-order conditioning, a sound source (either a damped bell or an oscillator tone) is employed.

Initially, six dogs were trained to respond (by lifting the electrode-leg over a bar) to the presentation of a uniform field of light appearing in the glass panel. The animal was credited with a correct response, and avoided the shock, when it lifted its leg as high as or over the bar, which was mounted about two inches above the floor. The light and shock were regulated by a timing device, and could be presented at intervals or multiples of these intervals at the discretion

of the experimenter. The timer was located in a sound-proof box in an adjacent room, in order to avoid auditory cues. Temporal conditioning was eliminated as completely as possible by varying at random the intervals between stimuli.

In the case of Subject I, the preoperative criterion was 18 conditioned responses out of 20 consecutive trials in a single trial period, including the occurrence of extraneous responses. This last qualification was dropped after the initial part of the training of Subject II, and in all the training of the remaining animals, since otherwise it would have been difficult to equate the learning of the different subjects. Accordingly, in all animals but Subject I, responses occurring before the presentation of the light were not considered as trials. During conditioning, these 'random' responses were usually punished with a light tap on the knee. It should be noted that, in general, over-learning was more than avoided because of the nature of the criterion. After the criterion of learning had been reached, extinction curves were obtained. Subsequently the animals were reconditioned and brought back to the previous level of responding.

From one to two weeks after this preoperative procedure, operations involving bilateral extirpation of the visual areas of the cortex were performed. After anesthetization of the animal with nembutal, the occipital lobes were exposed by the usual surgical methods, and were removed by means of an aspirator. Six animals were subjected to the operation, an attempt being made in each case to remove the visual cortex bilaterally without disturbing to any great extent the surrounding regions. Of the six animals, one (Subject VI) died before postoperative data could be obtained.

Five of the animals trained preoperatively were tested postoperatively from two to three weeks after operation. The postoperative testing was performed in a manner similar to the preoperative procedure, and reconditioning was carried out when necessary. After the criterion of conditioning had again been fulfilled, the response was extinguished. In the extinction series, 25 presentations of the light were given in each trial period, and, with the exception of Subject I, the extinction was continued until an insignificant number of responses (three or fewer) were obtained in a particular trial period.

In the third part of the experiment, four operated animals were used to investigate the possibility of establishing second-order conditioned responses to a sound stimulus, with the original light stimulus serving as the 'reinforcing' stimulus. In some preliminary observations, the method of training was that employed in the first-order conditioning, *i.e.*, the sound was presented, and if the animal responded, the light was omitted. After these initial observations, however, the procedure was changed to one in which the sound was invariably followed by light. If the animal failed to respond to both sound and light, an extra trial was then given in which the response to the light was reinforced by one paired presentation of light and shock. In this manner, Subjects I and II were trained to respond to a damped bell tone. Unfortunately, Subject II died before the criterion could be reached, but significant data were nevertheless obtained from this animal. Subjects I, IV, and V were conditioned to an oscillator tone as the second-order conditioned stimulus. Training with the bell had preceded this training only in the case of Subject I. This change in the stimulus (*i.e.*, from bell to oscillator tone) was made because the response to the light during the second-order training was often externally inhibited by the bell even though it was damped to a considerable extent. Extinction curves for the second-order reaction to the oscillator tone were obtained for Subjects I and V. Before the beginning of the second-order conditioning, each animal was initially tested with sound alone, to determine whether there was any generalization of the first-order response to the sound stimuli which were about to be used.

Different controls, which served to show the bona fide nature of the responses, were introduced in the course of the experiment. These control procedures will be mentioned at this point, and the results will be described later. For Subject V, the light reaching the milk-glass panel in the front of the projection apparatus was blocked off after the preliminary conditioning had been completed. With some of the animals, a motor which gave a loud masking hum was run during the final part of the first-order training in order to minimize possible extraneous auditory cues. The experimenter varied the times at which he keyed the timing circuit in order to destroy the effectiveness as cues of possible noises from the keys. Finally, the presentation of the sound stimuli alone at the beginning of the experiments on second-order responses served as control tests of the validity of the first-order responses to light, for if the animals had responded on the basis of extraneous cues during the primary conditioning, these stimuli would in all likelihood be present and would be serving to elicit a high percentage of responses when the sound was given.

C. Operations

In Fig. 2 are the photographs of the brains of the five operated dogs (Subjects I, II, IV, V, and VII) as viewed from the dorsal side, and of Subjects IV and V as viewed posteriorly. For comparison, a photograph of the cerebral cortex of a normal dog, on which the anterior boundary of the visual area is roughly indicated, is included in the figure. In the dog, the visual cortex is delimited by definite landmarks, *i.e.*, by the lateral sulcus, by the posterior lateral sulcus and its termination on the dorsal aspect of the cortex, and by the splenial sulcus on the medial aspect of the hemispheres.

In these operations, the tissue contained within and immediately surrounding the visual area was aspirated. The depth of the lesion was extended in every case through the tissue of the pallium into the ventricles. The opening in the ventricle was made first in the region just anterior to the recurrent sulcus, and was carried backward beyond the posterior limit of the splenial sulcus. Reference to the photographs, especially to the posterior views, will show that the ventricles were opened widely in every case but that of Subject I.

The brains of all five of the dogs were frozen, sectioned, and stained with thionin. Examination of cell degeneration in the external geniculate bodies and of the extent of the lesions in the cortex has indicated that our operations involved the entire area striata in all the dogs except Subject I and possibly Subject II. Our judgment of the extent of the lesion in Subject II is left open because of the failure to obtain adequately stained sections.

The behavior of the dogs postoperatively is significant in evaluating the success of the operations. All the animals except Subject I displayed the general loss of visual capacity which is invariably associated with destruction of the cortical visual areas in the dog or cat. In the case of Subject I, there was partial recovery of visual capacity; the dog eventually showed some ability to avoid objects and to respond to some extent to the movements of individuals. Visual placing reactions, however, were absent in this dog during the remainder of its life. The other animals lost as a result of the operation most, if not all, of their normal useful visual capacity. They had to be lifted from their cages to prevent falling, failed to avoid walls and other objects in their paths, showed difficulty in locating food placed before them, and possessed the hesitancy in gait and movement typical of a blind animal.

D. Results

The results of the experiment may be summarized with reference to three main topics as follows: 1. preoperative conditioning and postoperative reconditioning, 2. preoperative and postoperative extinction of the conditioned response, and 3. generalization and second-order elaboration of the conditioned response to light after removal of the visual areas.

1. *Preoperative Conditioning and Postoperative Reconditioning*

Table 1 summarizes the results secured during the initial conditioning of the six dogs. In the body of the table, the actual number of conditioned responses occurring during the daily 25-trial periods is indicated. At the bottom of the table is given the total number of trials required by each animal to reach the criterion, *i.e.*, 18 correct responses in 20 consecutive presentations of the light in any given trial period. It will be remembered that during the training of Subject I and during the initial training of Subject II, responses occurring before the presentation of the light were counted as trials. Thus these animals did not receive as many paired stimulus presenta-

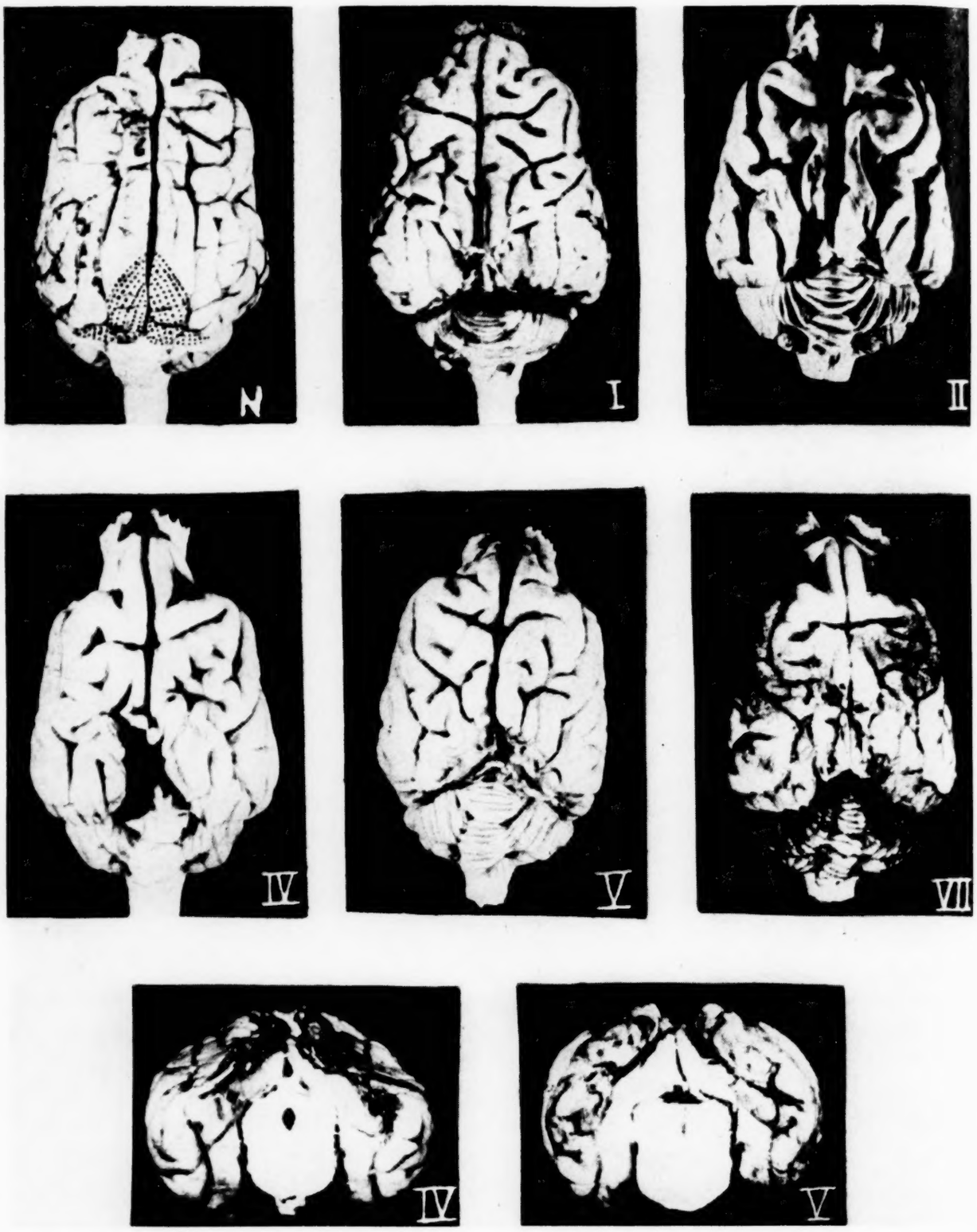

FIG. 2. Photographs of the brains of five operated dogs compared with a normal brain.

The stippling on the photograph of the brain of a normal dog (*N*) indicates the approximate extent of the visual area. The posterior views of the brains of Subjects IV and V indicate the extent to which the ventricles were opened in these animals.

TABLE 1

THE NUMBER OF CONDITIONED RESPONSES IN 25 TRIALS ON SUCCESSIVE DAYS DURING INITIAL PREOPERATIVE CONDITIONING

Subjects	I *	II *	IV	V	VI	VII
Trial periods						
1	0	0	0	1	1	2
2	0	0	0	5	0	8
3	3	0	0	3	0	7
4	10	0	0	17	1	16
5	15	4	1	22	0	19
6	10	8	5	19	0	20
7	20	4	12	24	2	22
8	16	0	19		14	
9	16	2	23		22	
10	20	9				
11	20	7				
12	19	3				
13	11	1				
14	12	8				
15	20	11				
16	19	18				
17	22	20				
18		24				
19		20				
20		23				
Total trials to fulfill Criterion	355	416	225	175	225	175

* During the training of Subject I and the initial training of Subject II, responses occurring before the presentation of the light were counted as 'Trials.' In this table, the 'total trials to fulfill Criterion' do not include these random responses.

tions per day as did the other subjects. The greater number of trials required by these two animals to learn the response is due in part to this difference in the criterion of learning. The range of trials required for conditioning to light in the dog in this situation varies between 175 and 416. It is evident that the number of trials originally required by Subjects I and II is not typical in this experiment, since with proper control of shock, and punishment for random responses, the other animals consistently gave better learning scores.

Preoperative reconditioning was carried out with all six animals after the initial conditioned response had been extinguished. The results for this reconditioning are summarized in Table 2. Subjects I and VII were reconditioned twice (Columns A and B respectively), since two extinction curves were obtained for the former, and since some measure of extinction accompanied an attempt at higher order conditioning with the latter. All animals reconditioned fairly rapidly except Subjects VI and VII (Series A), which required 75 and 100 trials respectively to fulfill the criterion of 18 conditioned responses in 20 consecutive trials.

TABLE 2

THE NUMBER OF CONDITIONED RESPONSES IN 25 TRIALS ON SUCCESSIVE DAYS DURING THE PREOPERATIVE RECONDITIONINGS

Subjects	I		II	IV	V	VI	VII	
Trial periods	A	B					A	B
1	21	20	21	18	23	13	15	24
2			22			18	19	
3						22	18	
4							23	
Total trials to fulfill Criterion	25	25	50	25	25	75	100	25

As described above, five animals were successfully subjected to the operation in which the optic cortex was removed bilaterally. Approximately two or three weeks after this operation, the five animals were reconditioned (if necessary) in the same experimental situation. The results, given in Table 3, show that the amount of

TABLE 3

THE NUMBER OF CONDITIONED RESPONSES IN 25 TRIALS ON SUCCESSIVE DAYS DURING POSTOPERATIVE RECONDITIONING

Subjects	I	II	IV	V	VII
Trial periods					
1	20	21	(20)*	18	23
2	18	14		21	
3	23	23			
Total trials to fulfill Criterion	75	75		50	25

* No shocks were administered, and extinction was begun immediately.

reconditioning necessary to bring the animals up to the criterion postoperatively was very small in comparison with the amount of training involved in the initial preoperative conditioning. Two animals (IV and VII) fulfilled the criterion in the first postoperative trial period, and no shocks were administered to Subject IV. Animals with more extensive lesions (IV, V, and VII) seemed to have retained the conditioned response as well as, if not better than, Subjects I and II, in which the lesions were somewhat less extensive.

Table 4 provides a comparison of the number of experimental days and shocks required in the original learning, in the preoperative reconditioning after extinction, and in postoperative reconditioning. It is at once evident that nearly perfect retention has been obtained in every case, as far as it may be judged from the data. The time required for postoperative reconditioning compares favorably with

TABLE 4

COMPARISON OF TRIAL DAYS AND SHOCKS IN ORIGINAL LEARNING, PREOPERATIVE RECONDITIONING, AND POSTOPERATIVE RECONDITIONING

	Days of Training			Shocks		
	Orig. Learng.	Preop. Recond.	Postop. Recond.	Orig. Learng.	Preop. Recond.	Postop. Recond.
Subject						
I	17	1	3	91	2	11
II	20	2	3	224	7	17
IV	9	1	0	203	7	0
V	7	1	2	94	2	11

the reconditioning before the operation, and in no case does it approach the original learning time. In order that the extent of the apparent retention may be further appreciated, the following description of the behavior of each animal on the first experimental evening after operation is presented:

Subject I: Ten conditioned responses before any shocks. Three shocks given in 25 trials.

Subject II: Four shocks given in the first 8 trials. Conditioned responses appeared in the remainder.

Subject IV: The record contained 20 conditioned responses in 25 trials. No shocks administered, and extinction was begun immediately.

Subject V: Five conditioned responses appeared before shocks were required. Seven shocks given in 25 trials.

Subject VII: Two shocks were necessary in the 25 trials, on the second and fifteenth trials.

2. *Preoperative and Postoperative Extinction of the Conditioned Response*

Table 5 summarizes the data relative to the preoperative and postoperative extinction of the conditioned response, indicating the total

TABLE 5

COMPARISON OF THE TOTAL NUMBER OF TRIALS DURING PREOPERATIVE AND POSTOPERATIVE EXTINCTION

Subjects	I *	II	IV	V	VII
Preoperative.....	A 43 B 120	200	100	75	175
Postoperative.....	553	425	275	110	425

* Extinguished and reconditioned twice before operation; failed to extinguish in 553 trials postoperatively.

number of trials required for extinction. It is to be noted that Subject I was conditioned and extinguished twice before the operation. The first extinction of the response in this animal was very rapid, but after reconditioning to the criterion, its responses were thereafter more resistant to obliteration by extinction. Subject V likewise portrayed rapid extinction of the reaction in the preoperative extinction series. A large degree of variation in resistance to extinction is revealed by the data in the table, and is brought out more clearly in Fig. 3, in which the two extinction series are graphically

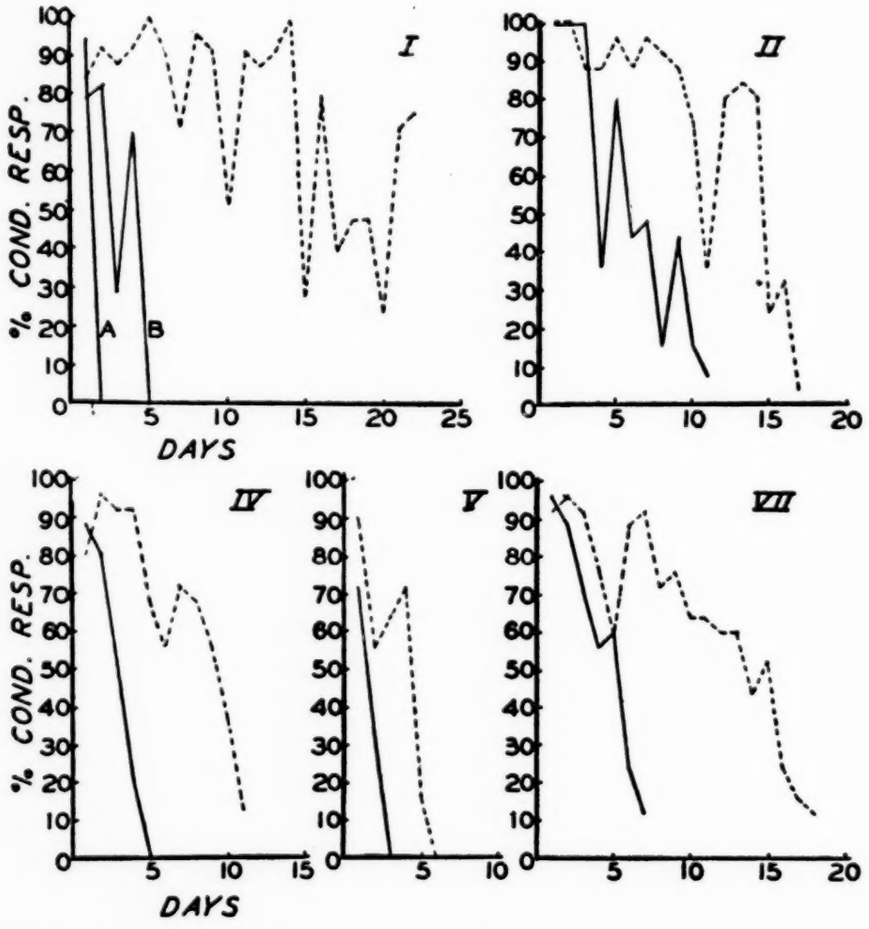

FIG. 3. Comparison of preoperative and postoperative extinction curves.
The solid lines indicate preoperative extinction, the dotted lines, postoperative extinction. There are two curves of preoperative extinction for Subject I, labeled *A* and *B*.

described. In these graphs, preoperative extinction curves are shown by solid lines, postoperative curves, by barred lines. The points plotted represent the percentage of conditioned reactions on consecutive days. It is important to note that the postoperative rate of extinction is much slower in every case than that found preoperatively. This is true even for Subject I, which was extinguished twice before operation. In the second preoperative extinction series for this animal, only 120 trials were needed to fulfill the criterion for

extinction (three or fewer CR's in 25 trials), whereas in the postoperative extinction, the criterion was not fulfilled in 553 trials. Postoperatively increased resistance is also marked in Subjects II, IV, and VII, in which the rate of extinction was relatively rapid before operation. The results seem to indicate very clearly that the conditioned light stimulus becomes a more effective agent in maintaining the learned response after operation, even in the absence of additional reinforcement in the postoperative period (as in the case of Subject IV, which received no shocks after operation).

Four of the animals in which the response to light was extinguished postoperatively (I, II, IV, and V) were reconditioned directly after the extinction series had been completed. Two dogs (I and IV) required respectively only 2 and 3 presentations of the unconditioned stimulus in order to fulfill the criterion. For the other two, three days of training were necessary, but each gave more than 20 responses on the second and third days. Reconditioning after extinction in these operated animals appears, accordingly, not to be significantly different from that observed when they were in the normal state. It is noteworthy that these results imply a considerable degree of spontaneous recovery of the conditioned response after extinction in animals lacking the optic cortex.

3. *Generalization and Second-order Elaboration of the Conditioned Response to Light after Removal of the Visual Areas*

Pavlovian theory of conditioning (7) is built mainly on the belief that inhibition, generalization, and second-order association of conditioned responses are based upon processes of interaction between focal points of activity in the cortex, and that the nature of this interaction defines the quantitative characteristics of these different processes. The experiments on extinction, already described, indicate that extinctive mechanisms operate in the absence of the primary cortical sensory areas associated with the conditioned stimulus. It remains to be ascertained whether, similarly, generalization and second-order elaboration of the light-conditioned response may occur following removal of the visual centers of the cortex.

In order to test experimentally whether or not second-order association of conditioned reactions may occur in the absence of the cortical projection areas of the conditioned stimulus, we have attempted to train operated dogs, already responsive to light as a CS, to respond to a sound stimulus by pairing it with the light, the latter serving as a 'reinforcing' stimulus. The sound was never directly associated with the electric shock, and hence it is presumed that any reactions established to the sound arise as a result of the connection the sound acquires with the light. If the conditioned response to

the light is referred to as a first-order CR, then any reactions to the sound which are established by virtue of its temporal relation to the light may be called responses of the second order, since the reaction to the sound is two steps removed, so to speak, from the original unconditioned response to the electric shock.

Four animals (I, II, IV, and V), which had been extinguished and reconditioned postoperatively (as described above), were used in this part of the experiment. In one series of observations with Subjects I and II, a bell was used as a second-order conditioned stimulus. Before starting the training, the bell was presented alone for 10 trials, but it failed to evoke a response in either animal. An attempt was then made, by presenting the sound for three seconds and following it directly with the light, to establish second-order conditioning to the bell. This procedure was unsuccessful, for the sound consistently inhibited the response to the light. That is, not only did the dogs fail to respond by generalization to the bell or to learn to respond to it by second-order conditioning, but also when the bell was presented before the light, the response to the latter (present when the light was given alone) was absent. The sound of the bell was then made low in intensity by damping, and in ten test trials using the damped bell alone, Subject I gave four responses and Subject II, one response. Training thereafter proceeded with the damped bell, but was eventually discontinued because in spite of the damping, the response to the light was often inhibited when the sound was presented in the regular second-order conditioning sequence. In instances where the animal gave no response to the bell-light presentation, a reinforcing trial with the light combined with shock was given.

In a further series of observations on Subjects I, IV, and V, an oscillator tone of low intensity was used as the second-order conditioned stimulus, combined with the light as the 'reinforcing' stimulus. At the start of this training, the light was omitted whenever the animal responded to the tone, but for the major part of this series, the light was always given following the presentation of the tone. Before the animals were presented with the paired stimuli, the oscillator tone was presented alone for 25 trials. In these preliminary control tests, Subject I gave 3 responses to the tone alone, Subject V gave no responses, and Subject IV gave 18 responses to the 25 stimuli. These seemed to be true generalized reactions, since this dog would not respond in the light situation when the light was turned off and showed otherwise that it was not reacting to extraneous cues before these tests with the oscillator tone were carried out.

The progress of learning in second-order conditioning is graphically indicated in Fig. 4. The various curves describe the process of

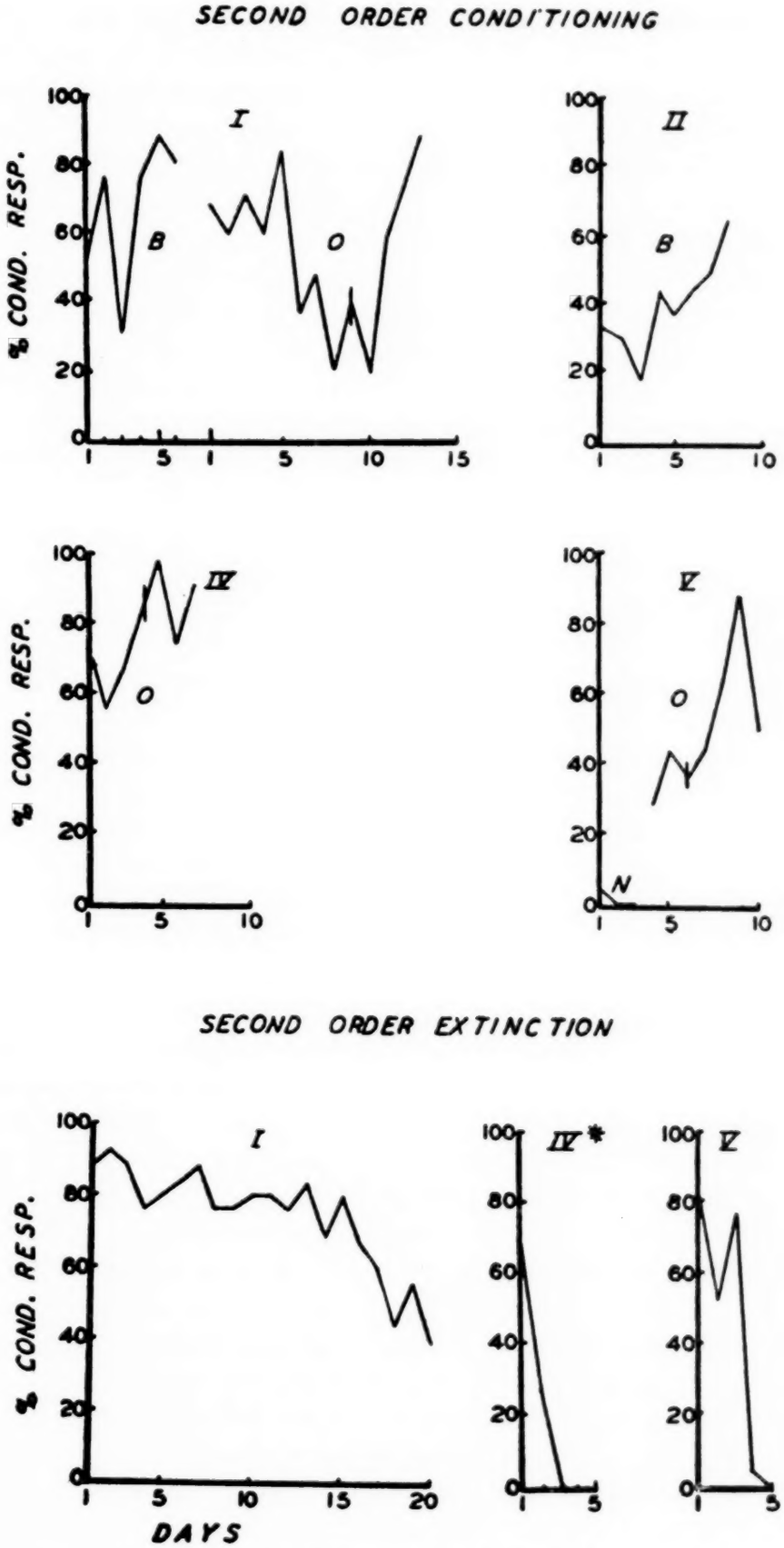

FIG. 4. Curves of Learning and of Extinction in Second-order conditioning.

Conditioning to a bell is indicated by *B* and to an oscillator tone, by *O*. The extinction curve of Subject IV represents the extinction of a generalized response to an oscillator tone. For further description see text.

conditioning to a bell (*B*) and to the oscillator tone (*O*). The curve marked (*N*) represents the progress of Subject V in acquiring a response to the oscillator tone when the response to light was not maintained by reinforcement with shock in separate trials. The results for second-order conditioning to the bell do not represent the complete training of Subjects I and II in the problem, for this final training was preceded by 200–300 trials of unsuccessful experimentation with louder bell sounds, during which the second-order conditioning was interfered with by the inhibiting effect of the auditory stimulus. The trials given here occurred in a period of training in which the intensity of the sound of the bell was reduced considerably. The curves shown for the learning of the second-order conditioned response (the top four graphs in Fig. 4) illustrate that second order conditioning to sound proceeds in a variable manner from an original level of generalization and does so relatively rapidly when the response to light is reinforced with shock in separate trials. Some of the variability noted in the learning is the result of a change in procedure (indicated on the curves by vertical lines) in which the light stimulus was made to follow the sound whether or not the animal responded to the auditory stimulus. Initially, the light was omitted if a response to the sound took place. It is to be noted that, in general, these operated animals learned the second-order response to sound with as much facility as normal animals, although actual data describing such learning in normal animals have not been submitted here. Furthermore, it has been found that second-order conditioning in the dog proceeds with considerably greater difficulty if the animal is first conditioned to sound and is then required to react to light as a derived response of the second order.[1]

It may be shown that the conditioned response to the sound is a bona fide derived reaction, dependent upon the reinforcing effects of its association with the learned reaction to light. It has already been stated that Subject V gave no generalized responses to the oscillator tone in the series of 25 test trials preceding the second-order conditioning. Before this dog was conditioned to the sound according to the final procedure which was adopted, it was tested over a period of three days (during which 25 trials were given each day) with the presentation of the sound and light together in the typical program of second-order conditioning, except that the response to the light was never reinforced by shock if the light failed to evoke a reaction (curve *N*, Fig. 4). The dog displayed only a few reactions to the sound in this training, and its reaction to light was partly extinguished. Thereafter, when the strength of the response to the light was maintained in separate trials by shock reinforcement, the dog

[1] Unpublished data from this Laboratory.

eventually learned to respond to the sound through its connection with the light-conditioned response. The response to the tone, in other words, was 'reinforced' by the light stimulus when the reaction to the light was maintained at its maximum strength, and the learning of the response to sound was based directly on the 'reinforcing' effects of the light.

Evidence that the derived responses to the sound are true second-order reactions rests upon a demonstration that the animal, in the primary conditioning to light, did not become conditioned to some extraneous auditory cues. There were two possible sources of such stimuli in the first-order training: sounds from the experimenter's switch which was used to key the automatically timed circuits of the light and shock, and possible clicks of the projection light as it was turned on. Since the former bore no constant relation to either light or shock (the keying could be done at any time within a 30-second interval before the final closing of the stimulus circuits by the timer), it was easy to discover any responses which might be attributable to this source. It was shown by each experimenter, independently, that none of the animals would respond during or after conditioning when the key was depressed. Any sounds produced by the onset of the light, which might have been present during the first few days of training for Subject I and II, were controlled by enclosing the projector in sound-proofing material. That an effective control of this possible source of stimulation was obtained was shown by check tests during which the light was blocked from the milk-glass panel. The light was then turned on as usual, but the panel remained dark. Dogs which had reached or exceeded the criterion of conditioning gave an insignificant number of responses. Other sources of sound were controlled by placing the timer in another room, separated from the experimental room by a thick wall. On the basis of these controls and from the fact that all animals but Subject IV failed to display a significant number of responses to the bell or oscillator tone directly after the primary conditioning to light, the evidence seems to be valid that the subsequent acquisition by the dogs of the derived response to sound stimuli represents a true second-order conditioning of avoidance reactions.

Observations relative to the extinction of the second-order conditioned responses to auditory stimulation provide additional information concerning the status of these reactions as compared to that of the primary conditioned responses to light. In Table 6 are given the data for the extinction of the responses to the oscillator tone for Subjects I and V, compared with the extinction of the generalized response to the oscillator tone in the case of Subject IV, which displayed a significantly high number of responses to the tone

TABLE 6

THE NUMBER OF CONDITIONED RESPONSES TO SOUND IN 25 TRIALS ON SUCCESSIVE DAYS DURING HIGHER ORDER EXTINCTION

Subjects	I	IV	V
Trial period	O	S	O
1	22	18	20
2	23	6	13
3	22	0	19
4	19		2
5	20		0
6	21		
7	22		
8	19		
9	19		
10	20		
11	20		
12	19		
13	21		
14	17		
15	20		
16	17		
17	15		
18	11		
19	14		
20	10		
Total trials.....	500	75	125

O—Extinction of response to combined presentation of oscillator tone and light.
S—Extinction of generalized response to oscillator tone alone.

before second-order conditioning was carried out. These data are presented graphically in the lower part of Fig. 4. In the case of Subject I, the response to the tone was difficult to extinguish. It will be remembered that this dog was trained extensively with a damped bell as a second-order stimulus before the response to the oscillator tone was established. Subject V extinguished to the tone in 125 trials, while the generalized reaction of Subject IV was abolished by extinction in 75 trials.

The results of these observations dealing with second-order reactions in dogs after occipital lobectomy may be summarized by saying that the dynamic properties of stimulus inhibition, generalization, second-order elaboration, and extinction of second-order reactions in conditioning are present even though the cortical projection areas of the primary conditioned stimulus have been destroyed.

E. DISCUSSION

The observations which have been described, although of a preliminary nature, have direct bearing upon several distinct problems related to the general questions of the neural basis of vision and of learning.

1. The Retention of Conditioned Visual Responses after Extirpation of the Occipital Lobes

The complete bilateral extirpation of the striate areas of the cerebral cortex in the dog does not abolish a conditioned motor response (hind-leg flexion) to light, although retention of the response after operation may be reduced in some animals. Accordingly, the conditioned avoidance reaction to light in the dog seems to be affected by the operation in a manner similar to that of the conditioned lid response as studied by Marquis and Hilgard (**5**, **6**). These results contrast sharply with the effect of the same operation upon visual intensity discrimination reactions in the rat (**3**), cat (**8**), and dog (**4**), which lose the habit and regain it only after extensive postoperative training.

Two possible explanations for this difference suggest themselves. In the first place, the discrimination response involves localization of the different light intensities, whereas the conditioning situation ordinarily does not require this. Secondly, the conditioned avoidance response may be acquired through a type of learning different from that involved in the establishment of the discrimination reaction. The former represents a sort of learning, having as its basis elements of Pavlovian conditioning as well as general anxiety motivation and reward through escape. Discrimination, on the other hand, involves, besides avoidance, specific reward learning maintained by hunger motivation. The question still requiring answer is which of these two differences is more important in explaining the inequality of the disturbance resulting from removal of the striate areas. Unpublished results, obtained with the cat by Bridgman in this laboratory, seem to minimize the importance of localization. It was found that the response of pressing a pedal upon presentation of a light was abolished by removal of the visual cortex, just as is the case with a specific discriminative reaction. In this experiment, the cats were rewarded with food for pressing a pedal when the stimulus light was turned on, and punished by shock for making this response in the absence of the light. Localization played an insignificant role in this situation because the animal was placed in a small compartment and had merely to step forward with one paw in order to press a large pedal mounted in the floor before the light screen, which covered the entire end of the box.

It is believed, therefore, that inherent differences between avoidance conditioning and discrimination learning are probably to be considered as more significant in accounting for the fact that loss of the occipital lobes destroys the visual intensity discrimination response but leaves the other relatively intact; and this implies, further,

a difference in the neural basis for these two types of learning. It is hoped, by means of experimentation now planned, that a definite conclusion regarding this question may be given in the near future.

2. *The Extinction of the Conditioned Response to Light after Removal of the Visual Areas of the Cortex*

A noteworthy result of this study has been the finding that the extinction of a conditioned response to light after the operation proceeds much more slowly than it does beforehand. This was true of all five animals. Since the procedure involved extinction of the CR before the operation, as well as afterward, it might be judged that the increase in the second extinction time was caused by the post-operative reconditioning. In the case of Subject IV, however, no reconditioning was required, and no more than seven reinforced trials were needed to bring Subject V to the criterion. One animal (I), which was extinguished and reconditioned twice before operation, showed little or no evidence of extinction after 22 days of testing following operation. Although completely adequate control observations have not been made concerning this point, the results suggest that the operation served to increase resistance to extinction beyond that limit which would have been fixed normally by the successive periods of reconditioning. We find it tempting to draw a parallel between this phenomenon and the normal inhibitory control which the striate areas impose upon the optic nystagmus produced by rotation of the visual environment of the cat and guinea pig (**9**, **10**, **11**, **12**, **13**). With both of these animals, visual stimulation appears to become a more effective agent in releasing reactions after the cortical optic centers have been destroyed.

3. *Postoperative Inhibition and Generalization with Regard to Auditory Stimuli of a Conditioned Response to Light*

It was observed in the course of the experiment that, after elimination of the optic projection centers of the cerebral cortex, the conditioned response to light may be inhibited by the sound of a loud bell presented one to three seconds before the light. It was also found that, in some cases, the conditioned response may be generalized to a weak oscillator tone. This generalization appears in animals which will not react to noises occurring at random in the usual experimental situation. These observations seem to provide evidence against the traditional Pavlovian concept of conditioning, for if the cortical projection areas of the afferent path of the CS are destroyed without abolishing generalization and inhibition of the CR, an explanation is required which does not depend simply upon the irradiation of

excitatory or inhibitory processes in the cortex. We suggest, therefore, that generalization and inhibition in conditioning are not the result of associations between the sensory projection centers of the cortex, and that like the primary integrations in the conditioning process, they may be determined at lower levels.

4. The Establishment of Second-order Conditioned Reactions to Sound Stimuli on the Basis of Initial Conditioning to Light in Dogs Lacking the Occipital Lobes

Our observations concerning this problem, which were designed especially to evaluate the Pavlovian concept of cortical drainage and association, have been made with the assumption that if the optic projection centers of vision are destroyed, a conditioned response to light would lose its ability to form associative relations with other afferent sensory processes, since the visual paths have no direct communication with the cortex other than through the optic radiations. Accordingly, it should prove impossible, or at best relatively very difficult, to establish second-order conditioned responses to sound, which depend upon initial conditioning to light, in an animal which has suffered bilateral extirpation of the optic cortex. This was not the case, at least for the four animals investigated. All of these dogs acquired second-order CR's to sound postoperatively with a rapidity comparable to that displayed by normal animals. Like the extinctive, inhibitory, and inductive properties of conditioned avoidance reactions, therefore, the secondary 'reinforcing' properties of the primary conditioned response are maintained, at least in part, by subcortical centers, and the cortical projection areas of the first-order conditioned stimulus are not indispensible to them.

5. The Role of the Optic Centers of the Cortex in Intensity Discrimination as Indicated by Experiments on Avoidance Conditioning

A considerable number of experiments have been reported which show that, after extirpation of the striate areas of the cerebral cortex, a brightness discrimination habit established before the operation is abolished, and must be relearned. The interpretation of this observation by different writers (**1**, **2**, **4**) typically holds that normally the striate areas mediate brightness vision, but that when these regions are removed, subcortical mechanisms assume the task of determining the residual parts of this function after sufficient training. It is then concluded that the striate areas and the subcortical optic centers may function 'equivalently' in the mediation of brightness discrimination. Thus, the hypothesis is that the rat, cat, and dog actually lose temporarily their capacity for brightness discrimination after the

operation. The proponents of this view fail to recognize the possibility that the observed behavior deficit may depend entirely upon the fact that the type of learning involved in the reactions to brightness differences is what is chiefly affected by the operation. Our data seem to point in this direction, for the five dogs used in this experiment showed no appreciable response deficit when they were reintroduced to the test situation postoperatively. Consequently, it may be considered probable that the animals which have hitherto been used in brightness discrimination experiments have suffered no abolition of brightness vision as the result of the operation, and that the learned responses related to the discrimination may have been disorganized instead.

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EFFECT OF CHANGE IN MOTIVATION UPON HOMOGENEITY OF ERGOGRAMS [1]

BY MALCOLM G. PRESTON, RICHARD G. BROTEMARKLE AND EDWIN G. CAMPBELL

University of Pennsylvania

In a recent contribution to the study of the similarity of ergograms all taken from the same person, Gobey (**3**) has reported that the ergograms taken from the right arm, right middle finger, left arm and left middle finger are more alike in respect of their shape than they are in respect of either the amount of work done by the *S* in their creation or in the duration of the period during which the *S* labored before the onset of exhaustion. Gobey studied the homogeneity of ergograms taken from the same person by extending the concept of trait variability developed by Clark Hull (**4**) to the problem of ergogram similarity. It will be recalled that the problem of trait variability treats of the extent of the variability within the individual (as contrasted with the variability through a population of individuals) and is studied by reducing the raw scores of a battery of tests into standard scores and then studying the individual variabilities across the standard scores. Where in general the standard deviation of a distribution of standard scores across the battery is very small we may conclude that the individual yielding these scores is relatively homogeneous in respect of his performances on the battery. It is obvious that another way of regarding these results is by consideration of the extent to which the individual maintains his position in the various population distributions. Wherever he maintains the same position in the population distribution from test to test his standard deviation across the battery will be zero. As he tends to be heterogeneous in respect of his standard scores, he will tend to vary in respect of the positions which he takes in the various population distributions.

The mathematical relation between Hull's measure of trait variability and the coefficient of correlation (which may be taken as an index of the extent to which the individual maintains his position in the instance of two constituents of the battery) has been shown by the senior author (**5**) of the present paper. The relationship is:

$$\bar{V} = 1 - \frac{1}{n(n-1)} \sum_{j \neq k} r_{jk},$$

[1] The present experiment was supported by a grant in aid of research made by the Pennsylvania Chapter of the Society of the Sigma Xi to the senior author.

where $\bar{V}$ is the mean trait variance (not standard deviation), n is the number of tests in the battery and $\sum r_{jk}$ is the sum of the entries in the table of intercorrelations between the tests of the battery, excluding the reliability coefficients appearing on the principal diagonal of the matrix. With n tests there will be $n(n - 1)$ of these entries.[2]

To interpret $\bar{V}$ we may note that whenever on the average individuals tend to maintain the same position from test to test on the battery the observed value of $\bar{V}$ will be small, whenever on the other hand the individuals tend to scatter their positions from test to test on the battery, the observed value of $\bar{V}$ will be large, approaching 1 as a limit as the number of tests increases.

Gobey's application of the formula to his data showed that for number of pulls $\bar{V}$ was .417, for total work done $\bar{V}$ was .532, for percent of work done in the 4th quarter of the ergogram $\bar{V}$ was .392, for percent of work done in the upper half of the ergogram (the percent obtained by dividing the total work done into the work represented by the sum of the amounts by which each spike in the ergogram exceeded half the length of the longest spike) $\bar{V}$ was .412. In view of the meaning which attaches to $\bar{V}$ we may conclude that as between total work and number of pulls (or duration of the interval between the beginning of work and exhaustion) on the one side, and the percentages (representing the manner in which the *S* distributed his work during the working period) on the other, the *S* tends on the average to hold his position over the four ergograms to a greater extent when position is determined by the latter (the configurational aspects of the fatigue curve) than when the position is determined by the former (the quantitative aspects of his work). Accessory evidence led Gobey to the conclusion that the tendencies were independent.

A consideration of the foregoing facts invites the hypothesis that the similarity of the ergograms in either or both respects may be a function of the extent to which the individual maintains a constant level of motivation, since in Gobey's experiment the four ergograms taken from each of the *S*s were taken during a single experimental hour, and under constant conditions of motivation. To test this hypothesis the present experiment was performed.

Experimental Design

1. The apparatus used by Gobey for arm and finger ergograms and described elsewhere (2) was used in the present experiment.

[2] In the above formula it should be noted that what is given is the mean of the square of the variabilities, *i.e.*, the mean variance, not, as Hull originally proposed, the mean of the standard deviations. The discrepancy between the value studied here and the value used by Hull in his study of trait variability has no practical significance.

2. The 48 male *S*s coöperated in the experiment by appearing at two separate times, the two appointments being separated by an interval of one week.

3. On the first appointment the *S*s were read Gobey's instructions (3) and yielded four ergograms, one each on the right arm, left arm, right middle finger and left middle finger. As was the case with Gobey's experiment, the order in which these four ergograms was taken varied such that all possible orders of the four were equally represented in the results. Any given order was used with a given *S* by chance. In addition an effort was made to match Gobey's working conditions.

4. On the second appointment the *S*s yield ergograms on the right arm and right middle finger under the same conditions as obtained at the first session. A sham treatment of the records was then made (the *S* being behind a screen was deceived in respect of the treatment) and the *S* was given the following statement:

"Last week I studied the records you made in a number of ways and discovered that you were doing just a little better on the whole than the average of 100 women studied here last year. I think that you can do better than that. What I am going to do is to give you either some cigarettes or some gum provided your record indicates that you are doing both of two things, *i.e.*, pulling harder on each pull and making more pulls."

After this statement he was asked to make a record with the left arm. This record was then given a sham treatment and the *S* was read the following:

"Well, you did better—here is the cigarette (or gum) which you won. See if you can't do better on this next record so that you can win more."

The final record, on the left finger, was then taken.

5. The records were treated by counting and measuring the heights of the spikes and by computing for each the percentage of the work done in the first half, in the upper half, and in the final quarter of the ergogram.

6. To study the question at issue, $\bar{V}$ and the standard deviation of the distribution of V (5, p. 279) was calculated for the first session and for the second session for each of the five characteristics of the ergogram subjected to quantitative determination.

7. The experiment was executed in the Psychological Laboratory of the University of Pennsylvania in 1940, 1941 and 1942.

Results

An important requirement of the present experiment is that the incentive introduced prior to the production of the left arm and left finger ergograms in the second session produce a significant increase in the amount of work and in the duration of work in the case of these two ergograms and further, that no significant increase take place in the case of the first two ergograms taken in the second session (on the right arm and right finger) in respect either of amount of work done or duration. Table 1 presents, among other things, the facts on this question. In this table are shown the relevant statistics of the distributions of differences between the values obtained on comparable members in session 1 and session 2. If the incentive were successful, clearly the mean difference on left arm as well as left finger ergograms should exceed zero significantly while the mean difference on each of right arm and right finger ergograms should not exceed zero significantly. It is clear from the table that in the case of both amount of work done and duration of the working period a significant difference appears in the case of ergograms taken from the left side of the body since all relevant P values are less than .02 (all but one being less than .01). (The units in the case of work are

TABLE 1

STATISTICS OF DISTRIBUTIONS OF DIFFERENCES BETWEEN PERFORMANCES ON FIRST AND SECOND SESSIONS

Variable	Range	Mean	Median	S.D.	t	P
Right Arm (No Incentive)						
Work	−2800 to 3800	150	20	1158	.90	$.4>P>.3$
Pulls	−54 to 36	−1.25	−.5	14.97	.58	$.6>P>.5$
Percent First Half	−21 to 28	−1.08	−1	7.66	.97	$.4>P>.3$
Percent 4th Quarter	−12 to 13	.84	1.17	4.96	1.17	$.3>P>.2$
Percent Upper Half	−11 to 10	.69	.17	4.22	1.13	$.3>P>.2$
Right Finger (No Incentive)						
Work	−350 to 350	10.4	29.1	118	.61	$.6>P>.5$
Pulls	−57 to 21	−2.37	−1.0	14.76	1.11	$.3>P>.2$
Percent First Half	−23 to 20	−2.00	−1.83	7.89	1.76	$.1>P>.05$
Percent 4th Quarter	−8 to 17	1.23	1.21	4.87	1.76	$.1>P>.05$
Percent Upper Half	−26 to 18	−.46	.50	8.26	.39	$.7>P>.6$
Left Arm (Incentive)						
Work	−1200 to 2800	1092	1100	900	8.4	$<.01$
Pulls	−36 to 30	4.31	5.00	12.03	2.47	$.02>P>.01$
Percent First Half	−32 to 11	−1.97	−.75	7.36	1.86	$.1>P>.05$
Percent 4th Quarter	−9 to 15	.60	.66	4.63	.97	$.4>P>.3$
Percent Upper Half	−8 to 17	2.23	2.25	5.76	2.69	$<.01$
Left Finger (Incentive)						
Work	−200 to 450	126	125	154	5.69	$<.01$
Pulls	−15 to 76	10.3	7.4	15.8	4.7	$<.01$
Percent First Half	−17 to 13	−1.42	−1.1	5.67	1.76	$.1>P>.05$
Percent 4th Quarter	−7 to 9	1.23	1.75	4.26	1.98	$.05>P>.02$
Percent Upper Half	−33 to 15	.08	.90	8.32	.07	$>.90$

millimeters of distance as measured on the record. In the case of number of pulls the unit is the spike. Thus in respect of work done with the left arm the median change is an increase in work done of 1100 mm as measured on the record. In respect of work done by the right arm the median change is an increase of 20 mm as measured on the record. In respect of number of pulls the median change in the left arm is an increase of 5 pulls. In respect of number of pulls with the right arm the median change is an increase of .5 pull.) It is equally clear that no difference exists between either the amount of work or the number of pulls taken from the ergograms on right arm and finger since all P values are well in excess of .05. We may conclude, therefore, that the ergograms of the second session were taken under effectively heterogeneous conditions of motivation while relatively speaking, the ergograms of the first session were taken under homogeneous conditions of motivation.

Table 1 also gives the relevant statistics of the distributions of differences between the various percentages on comparable members from the first and second session ergograms. It will be observed that in all cases but one (percent upper half left arm) the P values exceed .02 and that the t value for the single significant statistic is 2.69. From these facts it is apparent that the introduction of the incentive had little systematic effect upon the percentage values.

Summing up the evidence from Table 1 it would appear that on the average the introduction of the incentive produced significantly more work in the instance of the ergograms affected by the incentive, but in addition the introduction of the incentive, on the average, produced insignificant changes in the form of the ergogram, *i.e.*, in the percentage values.

TABLE 2

CORRELATIONS BETWEEN PERFORMANCES WITH SAME MEMBER IN SESSIONS 1 AND 2

Variable	No Incentive		Incentive	
	Right Arm	Right Finger	Left Arm	Left Finger
Work	.61	.74	.70	.61
Pulls	.78	.37	.68	.32
Percent First Half	.38	.45	.33	.67
Percent 4th Quarter	.57	.41	.58	.51
Percent Upper Half	.68	.18	.47	.17

Table 2 gives the correlations between observations made on the same member in Sessions 1 and 2. The correlations involving right arm and right finger are in the nature of reliability coefficients since the conditions under which the ergograms were taken were comparable. The left arm and left finger coefficients cannot be regarded as reliability coefficients since the incentive was introduced just prior to the taking of the left arm and left finger ergograms in the second session. Coefficients are given for each of the four members and for each of the five characteristics of the ergogram under study. If those coefficients are examined which are in the nature of reliability coefficients it will be found that the degree of test reliability present is in most cases not considerable, the maximum coefficient being .78 and the minimum .18. However of the ten which appear in the table four are greater than .60. If the individual coefficients from the two arm ergograms are compared it will be observed that the five pairs are entirely comparable. The same fact is to be observed in the case of the finger ergograms. None of the differences between the paired coefficients (using the z-function to determine the significance of the difference between rs) are significant and no trend is to be observed over the whole set. We can conclude therefore

that despite the fact that the introduction of the incentive increased significantly the amount of work done with the left members, the reliability coefficients were left undisturbed by the introduction of the incentive. From this it would appear that strict homogeneity of incentive in the case of the individual subject is not necessary for the establishment of correlation between performances on ergograms.

TABLE 3

INTERCORRELATIONS BETWEEN MEMBERS, AND MEASURES OF TRAIT VARIABILITY

Variable	LA–LF	LA–RA	LA–RF	LF–RA	LF–RF	RA–RF	$\bar{V}$	S.D.$_V$
First Session								
Work	.26	.63	.36	.57	.67	.54	.495	.449
Pulls	.54	.61	.50	.27	.61	.16	.552	.514
Percent First Half	.48	.54	.21	.32	.68	.31	.577	.520
Percent 4th Quarter	.56	.65	.24	.48	.53	.28	.543	.494
Percent Upper Half	.14	.62	.19	.20	.23	.13	.748	.658
Second Session								
Work	.46	.86	.51	.47	.60	.41	.448	.435
Pulls	.45	.77	.44	.31	.40	.26	.562	.513
Percent First Half	.21	.59	.29	.41	.53	.32	.608	.541
Percent 4th Quarter	.44	.72	.30	.48	.49	.46	.518	.447
Percent Upper Half	.10	.56	.27	−.02	.42	.44	.705	.647

Table 3 gives the intercorrelations among the four members in the case of each of the five variables for each of the two sessions. The first part of the table gives the data for the first session when the conditions of motivation were relatively homogeneous. The second part of the table gives the data for the second session when the conditions of motivation were heterogeneous. In addition to the intercorrelations, Table 3 gives the Mean Trait Variance ($\bar{V}$) and the Standard Deviation of the distribution of Trait Variances (S.D.$_V$). As $\bar{V}$ approaches zero, the variation in position in the four distributions tends on the average to approach zero, *i.e.*, each person tends to maintain the same position in the four distributions. As $\bar{V}$ approaches 1.00, the tendency for the individual to maintain the same position in each of the four distributions breaks down completely on the average. The standard deviation of the distribution of trait variances measures the extent to which there is wide variation among the subjects of the experiment in respect of their individual tendency to maintain constant position. When this value is zero, everyone is alike in respect to his tendency to maintain a given homogeneity of position in the four distributions. As S.D.$_V$ approaches 1.00, wide differences among the *S*s appear in respect of the tendency to hold the same position in the various distributions.

Inspection of Table 3 shows that no significant tendency exists for the correlations to decrease or for the trait variance to increase as a result of the heterogeneous conditions of motivation in the second session. Further, if the values of $\bar{V}$ in the two sessions are systematically compared it will be observed that the order of magnitude of $\bar{V}$ in Session 1 is the same as the order of magnitude in Session 2. The likelihood of five perfect matches from five pairs in random sampling is less than .01 (1) and is therefore sufficiently remote for the sampling hypothesis to be rejected. The same correspondence is to be observed in the five pairs of S.D.$_V$. We regard the foregoing as supporting the reliability of the results of the experiment.

If the results of the present experiment are compared with the results of Gobey's experiment it will be seen that the present experiment confirms the former in respect of the order of magnitude of the individual coefficients of correlation. In both first and second sessions like members produce the highest coefficients and this is true no matter which of the variables is studied. However, in the most important respect the data of Table 3 do not confirm the results of Gobey's experiment. Examination of the coefficients in Session 1, in which the conditions were identical with Gobey's conditions except for the number of cases used (and for the fact that our Ss were males while his were females) shows that the mean trait variance for work is somewhat lower than the mean trait variance on the three percentage values. The same condition obtains in the instance of the second session. We are inclined to believe on the basis of these two instances that the slight superiority of the work in respect to mean trait variance is not an accident. In view of this fact, it cannot be maintained that there is a general tendency for individuals to be more similar in respect of the way in which they work than they are in respect of the amount of work they do. Gobey reported that the final quarter of the ergogram was most characteristic of the subject. The present experiment indicates that the percentage of work done in the fourth quarter (apart from the amount of work done) yields the smallest mean trait variance and with the exception noted above corroborates Gobey's assertion.

A final fact to be observed by comparing the data from Tables 2 and 3 is the fact that the coefficients between like members in first as well as in second session (as shown in Table 3) are indistinguishable from the reliability coefficients appearing in Table 2. There is as much correlation between right arm and left arm in the first session as there is between right arm records taken a week apart. From this fact it is clear that we can predict right arm performance from left arm performance as well as we can from another sample of right arm performance. Indeed in some cases an arm ergogram gives as good

prediction of a finger ergogram as does another finger ergogram taken a week previously. For the percent fourth quarter the reliability coefficient on right finger is .41 (see Table 2). For the same variable in the second session the correlation between right arm and right finger is .46.

Conclusion

The foregoing facts appear to be conclusive in their significance that the homogeneity which exists among ergograms taken from the same person is not attributable to homogeneity of the incentive level existing for that person. In addition evidence is presented which suggests that the homogeneity is not attributable to the taking of the records during the same sitting, since the reliability coefficients are based on records taken one week apart. There remain for testing additional hypotheses suggested by Gobey: 1. homogeneity may be due to constancy of the instructions under which the *S* works. 2. homogeneity may be due to selection of the weights used. 3. homogeneity may be due to constancy of the fatigue level at which the work starts. A choice among these alternatives can be made only on the basis of experiment.

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TESTS OF SENSORY PRE-CONDITIONING WITH HUMAN SUBJECTS *

BY W. J. BROGDEN

Department of Psychology, University of Wisconsin

INTRODUCTION

The phenomenon named sensory pre-conditioning was demonstrated in an experiment upon dogs reported by Brogden (1). This phenomenon may be briefly described as follows. A bell and a light were presented simultaneously 200 times to the subjects. When one of these two stimuli was made a CS [1] for conditioned forelimb flexion, by pairing it with electric shock to the forepaw, the other stimulus also evoked forelimb flexion. The bell and the light were neutral in eliciting forelimb flexion prior to this training procedure. The phenomenon was shown by control groups to be a function of the pairing of the bell and the light prior to one of them being made a CS, and not due to sensory generalization. Animals not given the bell and light in combination, when one of these stimuli was made a CS for forelimb flexion, failed to respond or responded infrequently to the other stimulus. It is assumed that some connection, some sensory conditioning, occurred during the presentation of the bell and the light, and that this was responsible for the evoking of the flexion-response by a stimulus which had never been paired with the US.

Several studies have been reported which bear closely upon this problem. The experiments of Prokofiev and Zeliony (7) and Shipley (8, 9) have been adequately discussed in relationship to the phenomenon of sensory pre-conditioning in the earlier publication (1). Since that time, Lumsdaine (6) repeated one of Shipley's experiments (8) and obtained essentially the same results. Studies of sensory conditioning under hypnosis and of conditioned hallucinations have been reviewed and discussed by Ellson (2) in his report of an experiment upon hallucinations developed by a sensory conditioning procedure.

The present investigation was designed to test the occurrence of

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[1] Abbreviations: US = Unconditioned (original) Stimulus; UR = Unconditioned (original) Response to US; CS = Conditioned Stimulus; CR = Conditioned Response; and GSR = Galvanic Skin Response.

the phenomenon of sensory pre-conditioning in human subjects by a procedure similar to that used in the experiment with dogs. An additional control group was introduced; an additional test of sensory conditioning was tried; and attempts were made to relate the phenomenon, if it occurred, to the verbal reports of the subjects.

Experimental Procedure

The light-shielded sound-insulated experimental room contained a chair and a table. Upon the table was a metal box with a sloping front panel with two symmetrically located apertures 2 inches in diameter. Attached to the inner surface of the panel and covering the apertures were a milk glass plate which could be illuminated by a 7 watt light bulb and a 2 inch loud speaker protected by copper wire screening. The positions of the loud speaker and the milk glass plate were interchangeable. A small vertical panel, just below the sloping front panel, contained a series of phone jacks. Polished copper electrodes mounted upon sponge rubber and attached to a leather strap were connected to a circuit for producing an electric shock stimulus by insertion of the plug into the suitable jack. Polished silver electrodes, mounted upon sponge rubber and attached to a leather strap, were connected to the Wheatstone bridge circuit used for recording the GSR by insertion of the plug into the proper jack. A multi-conductor cable was led from the metal box through an opening in the wall of the experimental room to the adjacent control room, where connection was made with the control and recording equipment. A 2 foot square window in the wall common to the experimental and control rooms contained an X-ray mirror and two additional plates of clear glass, all of different thicknesses. The X-ray mirror was on the side of the wall of the experimental room and appeared to be a mirror to the subject in that room. From the control room, where the illumination was less than that of the experimental room, visibility of the experimental room was excellent, the X-ray mirror functioning as a one-way visual screen. The different thicknesses of glass within the window attenuated the transmission of sound.

Access to the control room was obtained from a hall into which the door of the experimental room also opened. All apparatus other than that already mentioned as present in the experimental room was contained within the control room. An electric motor which was used as a noise screen masked the sounds produced by the action of the control and recording equipment so that the subject received no stimuli other than those intentionally delivered and controlled by the experimenter. The stimuli used in the experiment were the illumination of the milk glass plate in the box on the table in the experimental room, a complex tone of low pitch produced by activation of the loud speaker in the same box, and a high voltage electric shock led to the copper electrodes also located in the experimental room. These stimuli will hereafter be referred to as the light, the tone, and the shock. The light was produced by application of the 110 volt line current to a 7 watt electric light bulb placed behind the milk glass screen. The tone was produced by feeding the output of a vacuum tube oscillator into the loud speaker. The intensities of the light and tone were held constant at magnitudes which had been judged to be equivalent by four observers.[2] The shock was delivered by a uni-directional equal pulse stimulator. Any setting of the stimulator assured the delivery of a shock of constant intensity, even if there was a change in the resistance at the electrodes. The intensity of shock used varied from subject to subject, but was always maintained at a magnitude just sufficient to evoke an adequate GSR. The GSR was measured by the method of Féré, the subject being one resistance arm in a Wheatstone bridge circuit. A variable resistance in the circuit was used to balance the bridge before each trial. Change in the skin resistance of the subject, provoked by the stimulus conditions, destroyed the balance of the bridge circuit and produced deflection of a galvanometer. Photographic records of the GSR to the various stimuli and stimulus combinations were obtained by deflection of a light

[2] Four subjects were asked to judge whether the tone was greater, equal to, or of less magnitude than the light. The method of constant stimulus differences was used, with the light being the standard and the tone the variable stimulus. The subjects showed fair agreement with each other. The intensity of the tone used in the experiment was the mean of the midpoints of their intervals of uncertainty. Equation of the magnitudes of the tone and light was done for this experiment because of the different degrees of sensory pre-conditioning obtained to the bell and the light in the earlier experiment (1).

beam from the mirror attached to the moving coil of the galvanometer along the slit of a motor driven camera. The stimulus conditions and a time line were also obtained upon the record by the appropriate control of light beams.

The nature and occurrence of any trial was controlled by the operation of a master switch which operated a synchronous motor timer which in turn controlled the operation of a bank of relays. Once the appropriate events for a given trial had been selected by means of the proper switches upon the control panel, turning of the master switch set off a sequence of events which were exactly timed and reproducable. With any given trial, the motor of the camera was started 1/2 second before any stimulus was given and continued for 6 seconds after the termination of any stimulus. The light and the tone were always 4 seconds in duration and the shock was always 1/10 of a second in duration. During conditioning, when the light and shock were paired, the shock was always given at the termination of the light.

The subjects of this investigation were volunteers from the class in elementary psychology at the University of Wisconsin. Appointments were made in quiz sections for an experimental session. No information was given the subjects about the nature of the experiment, other than it would require not more than one hour of their time. A total of 80 subjects, 40 men and 40 women, were placed at random into four groups so that each group was composed of ten men and ten women.

Each subject was introduced into the experimental room and was asked to sit in the chair so that his arms could be rested comfortably upon the table. The experimenter cleansed the palm and back of the subject's right hand with ethyl alcohol and then strapped the silver electrodes to the prepared skin areas. The electrodes were adjusted so that there was positive contact between the surfaces of the electrodes and the skin, but within a pressure range which did not elicit reports of discomfort by the subject. These electrodes placed the subject in the Wheatstone bridge circuit. The polished copper electrodes for delivering shock were strapped to the inside of the subject's left wrist and were adjusted in accordance with the subject's reports of comfort. The subject was asked to select a comfortable posture and hold it during the course of the experiment, at the same time maintaining visual fixation upon the small metal box placed upon the table directly in front of him. For half the men and half of the women in each of the four groups, the glass screen covered the aperture to the left of that covered by the loud speaker. For the remaining subjects, the spatial relationship of the two was reversed. If the subject asked questions about the nature of the experiment, the questions were unanswered. All subjects were told that any questions which they might have would be answered when the experiment had been completed. The experimenter then left the experimental room and did not reënter it until the experiment was over.

Group I, the sensory pre-conditioning group, was first given 10 trials of the tone and light in combination; then 5 trials of the light alone; 25 trials of light plus shock;[3] 10 trials of tone alone; and finally 10 trials of light alone. Group II, which served as a control for sensory generalization in Group I, was first given 5 trials of light alone; 25 conditioning trials; 10 trials of tone alone; and then 10 trials of light alone. Group III, which served as a control for the pairing of the tone and light in Group I, was first given 10 trials of tone alone; then 5 trials of light alone; 25 conditioning trials; 10 trials of tone alone; and finally 10 trials of light alone. Group IV served as a control for the validity of the extinction series of the other three groups in measuring the phenomena under investigation. This group was first given 5 trials of light alone; then 25 trials of light plus shock; and finally 10 trials of light alone. The temporal intervals between trials were in all cases varied at random between 20 and 45 seconds.

When the experiment had been completed, the experimenter reëntered the experimental room and while releasing the subject from the apparatus, asked him questions and recorded the answers. All subjects were asked what they considered the nature of the experiment to be. If they answered 'conditioning,' they were asked to state the response being conditioned. The subjects in Groups I, II, and III were then asked if they expected to receive shock with the tone, when the tone was given immediately after the conditioning trials. If they answered affirmatively, they were asked why they expected to receive shock with the tone. The subjects in Group I were asked if the glass plate were illuminated concurrently with the tone in these same trials, in order to check on a conditioned synesthesia. All subjects were asked whether they expected to receive shock during the extinction series. They were also asked to state why they expected or did not expect to receive shock with the light in the extinction series.

[3] Twenty-five conditioning trials were chosen because Hovland (5) has shown that sensory generalization of the GSR is minimal with this number of reinforcements.

Measures of the latency and magnitude of the GSR's were obtained from the photographic records. Latency was measured to the nearest 1/10 of a second. If no response occurred during the 4 second duration of the stimulus, the maximum latency of 4 seconds was assigned to that trial. Amplitude was measured to the nearest millimeter of deflection and was then transferred to resistance change in ohms. The amplitude measure recorded to the light or tone was the maximum deflection obtained during the 4 second duration of the stimulus. The CR's recorded were thus always anticipatory responses. This procedure was followed in all cases, no matter whether shock was given or not. Mean magnitude and mean latency were computed for the different stimulus conditions for each subject. Group means of the individual mean magnitude and mean latency were thus obtained, together with the mean frequency of response for each group. These measures were used as representative of the performances of the four groups.

Quantitative Results

Before the tests for sensory conditioning can be considered valid, it is essential to determine whether the different groups are similar

TABLE I

The group means for magnitude, latency, and frequency of GSR are given for each group for all of the different conditions of stimulation. The figure in parentheses to the right of each mean is its standard error. The letters M, L, and F in the extreme left hand column of the table represent respectively magnitude in ohms, latency in seconds, and frequency in terms of the number of responses. The phrase '10 Trials T + L' refers to the conditions obtaining for the data upon which the means immediately below it were computed. The other phrases bear a similar relationship to the data immediately below them. In all phrases, the tone stimulus is represented by 'T,' and the light stimulus by 'L.'

	Group I		Group II		Group III		Group IV	
	10 Trials T + L				10 Trials of T			
M	4490	(578)			1900	(399)		
L	2.44	(.11)			2.71	(.14)		
F	8.45	(.41)			6.35	(.57)		
	5 Trials of L							
M	1690	(567)	2050	(333)	3050	(1122)	3050	(486)
L	3.00	(.17)	2.97	(.56)	2.71	(.16)	2.54	(.17)
F	2.75	(.39)	2.70	(.14)	3.30	(.34)	4.00	(.33)
	Last 10 Trials of L + Shock							
M	3160	(621)	2830	(563)	2250	(479)	5350	(956)
L	2.56	(.13)	2.48	(.14)	2.61	(.14)	2.24	(.11)
F	8.05	(.53)	7.70	(.57)	7.40	(.64)	8.60	(.44)
	10 Trials of T							
M	2840	(564)	2700	(496)	1820	(600)		
L	2.90	(.11)	2.69	(.14)	3.12	(.12)		
F	6.30	(.56)	6.45	(.60)	4.45	(.57)		
	10 Trials of L							
M	1940	(551)	1350	(701)	1340	(439)	2230	(495)
L	3.18	(.12)	3.10	(.14)	3.15	(.15)	2.72	(.14)
F	4.85	(.67)	5.00	(.68)	4.55	(.71)	6.60	(.54)

in the sensitivity of the GSR to stimuli given before conditioning, and also in the degree of conditioning attained in the 25 conditioning trials. All groups were given 5 trials of the light alone before the conditioning trials were given. The mean magnitude, latency, and frequency of the GSR to these trials are given for each of the four groups in Table I. In Table II, the differences between the four

TABLE II

DIFFERENCES IN GSR TO LIGHT ALONE PRIOR TO CONDITIONING

The numerals in the left hand column refer to the different groups in the experiment. The figures in the columns headed by 'D' are differences between the means of the groups compared. The standard errors of the differences are given in the columns with 'σ_D' at the top. In the columns headed by 'p' are given the probabilities that such differences might be expected to occur when 100 samples are drawn at random from a homogeneous population.

Groups	Magnitude			Latency			Frequency		
	D	σ_D	p	D	σ_D	p	D	σ_D	p
I–II	−360	(660)	.31	+0.03	(.59)	.47	+0.05	(.42)	.46
I–III	−1360	(1257)	.15	+0.29	(.24)	.12	−0.55	(.52)	.15
I–IV	−1360	(747)	.04	+0.46	(.24)	.03	−1.25	(.51)	.01
II–III	−1000	(1170)	.21	+0.26	(.58)	.33	−0.60	(.37)	.05
II–IV	−1000	(589)	.05	+0.43	(.59)	.24	−1.30	(.36)	.01
III–IV	0			+0.17	(.24)	.24	−0.70	(.47)	.07

groups in magnitude, latency, and frequency of GSR to light are given. These differences were subjected to Fisher's t test in order to determine their reliability (**3**). If the p value indicates that such a difference might be expected to occur 5 or less times out of 100 samples drawn at random from a homogeneous population ($p = .05$ or less), the difference is considered to be a reliable one. Groups I, II, and III show no reliable differences between each other except in the case of Groups II and III, where Group III shows a reliably greater frequency of response than that given by Group II. Group IV gave a response with reliably greater magnitude than that given by either Group I or Group II, but showed no difference with Group III. With the latency of response, Group IV showed a reliable difference with Group I, but no difference with either Group II or III. Group IV gave a reliably greater frequency of response than that of both Groups I and II, but did not differ reliably from Group III. As far as sensitivity of the GSR to light alone is concerned, Groups I, II, and III seem to be representative of the same population. Group IV may be representative of a different population. There is no indication that giving 10 trials of light plus tone (Group I), or 10 trials of light alone (Group III) makes any difference in the sensitivity of the GSR to light alone, since Groups I and III show

no consistent differences in response to that given by Groups II and IV.

As a measure of conditioning, the mean magnitude, latency, and frequency of GSR to the light during the last 10 trials of light and shock were taken. These statistics are given in Table I for each group. Table III gives the differences in the conditioning measures

TABLE III

DIFFERENCES IN CONDITIONED GSR'S DURING LAST 10 CONDITIONING TRIALS

The numerals in the left hand column refer to the different groups in the experiment. The figures in the columns headed by 'D' are differences between the means of the groups compared. The standard errors of the differences are given in the columns with 'σ_D' at the top. In the columns headed by 'p' are given the probabilities that such differences might be expected to occur when 100 samples are drawn at random from a homogeneous population.

Groups	Magnitude			Latency			Frequency		
	D	σ_D	p	D	σ_D	p	D	σ_D	p
I–II	+330	(838)	.35	+0.08	(.19)	.34	+0.35	(.70)	.31
I–III	+910	(784)	.12	−0.05	(.19)	.38	+0.65	(.83)	.21
I–IV	−2170	(1140)	.03	+0.32	(.17)	.03	−0.55	(.69)	.21
II–III	+580	(739)	.21	−0.13	(.20)	.26	+0.30	(.66)	.33
II–IV	−2520	(1109)	.01	+0.24	(.18)	.10	−0.90	(.72)	.11
III–IV	−3100	(1069)	.01	+0.37	(.18)	.02	−1.20	(.78)	.06

for each group comparison. There are no reliable differences in the measures of conditioning between Groups I, II, and III. Group IV has a reliably greater magnitude of response than that of Groups I, II, and III, a reliably shorter latency than that of either Groups I or Group III, but shows no reliable difference in the frequency of conditioning. The degree of conditioning, then, is the same for Groups I, II, and III, with that of Group IV being greater with respect to magnitude, and probably latency.

It should be demonstrated that the conditioning trials resulted in conditioning; in other words, that there was a greater magnitude, shorter latency, and greater frequency of response to the light during the latter trials than to the light alone before conditioning. Examination of the differences between the magnitude, latency, and per cent frequency of response during the last 10 conditioning trials and that during the 5 trials of light alone before conditioning reveals this to be true with one exception (Table IV). However, not all of the differences are reliable ones. Only Group I shows a reliably shorter latency and reliably greater magnitude and percent frequency of response during the last 10 trials of conditioning than during the 5 trials of light alone prior to conditioning. Group II shows a reliably greater percent frequency of response, but no reliable

TABLE IV

DIFFERENCES IN GSR TO LIGHT BEFORE CONDITIONING AND DURING LAST 10 TRIALS OF CONDITIONING

The last numerals in the left hand column refer to the different groups in the experiment. The figures in the columns headed by 'D' are differences between the means of the GSR's to the last 10 trials of conditioning and the 5 trials of light alone prior to conditioning. A plus sign indicates that the difference is in favor of the responses given during the conditioning trials. The differences and their standard errors in the columns below Frequency are in terms of percent. The standard errors of the differences are given in the columns with 'σ_D' at the top. In the columns headed by 'p' are given the probabilities that such differences might be expected to occur when 100 samples are drawn at random from a homogeneous population.

Group	Magnitude			Latency			Frequency		
	D	σ_D	p	D	σ_D	p	D	σ_D	p
I.....	+1450	(841)	.04	−0.44	(.22)	.02	+25.50	(9.43)	.01
II.....	+780	(654)	.12	−0.49	(.58)	.21	+21.00	(6.15)	.01
III.....	−800	(1266)	.27	−0.10	(.21)	.31	+8.00	(9.34)	.30
IV.....	+2300	(1090)	.02	−0.30	(.20)	.07	+6.00	(7.93)	.33

differences with respect to magnitude or latency. There are no reliable differences at all for Group III, and it was with this group that the one exception occurred (magnitude). The difference in magnitude is the only reliable difference for Group IV. Since the unconditioned GSR to a stimulus such as the light is subject to rapid negative adaptation, there is good evidence that conditioning did occur with all groups during the 25 training trials of light and shock.

The subjects of Group I, after having been given 10 trials of the tone and light together, and then 25 conditioning trials of the light plus shock, responded to the 10 trials of tone alone with a mean magnitude of 2840 ohms (σ = 564 ohms), with a mean latency of 2.90 seconds (σ = 0.11 second), and with a mean frequency of 6.30 responses (σ = 0.56 response) (Table I). If the response of this group to the tone is a function of sensory conditioning occurring when the tone and light were given together it must be shown that their response to the tone is significantly greater than the response given to tone by the subjects in Groups II and III, where there was no possibility of sensory conditioning. It must be demonstrated that the response to the tone by Group I is neither a function of sensory generalization, of the tone having been given alone prior to conditioning, nor of both of these factors. The subjects of Group II, when presented with 10 trials of the tone alone after conditioning of the GSR to light, responded with a mean magnitude of 2700 ohms (σ = 496 ohms), with a mean latency of 2.69 seconds (σ = 0.14 second), and with a mean frequency of 6.45 responses (σ = 0.60

response). Those of Group III responded to the 10 trials of tone with a mean magnitude of 1820 ohms (σ = 600 ohms), a mean latency of 3.12 seconds (σ = 0.12 second), and a mean frequency of 4.45 responses (σ = 0.57 response) (Table I).

TABLE V

DIFFERENCES IN GSR TO TONE ALONE AFTER CONDITIONING TO LIGHT

The numerals in the left hand column refer to the different groups in the experiment. The figures in the columns headed by 'D' are differences between the means of the groups compared. The standard errors of the differences are given in the columns with 'σ_D' at the top. In the columns headed by 'p' are given the probabilities that such differences might be expected to occur when 100 samples are drawn at random from a homogeneous population.

Groups	Magnitude			Latency			Frequency		
	D	σ_D	p	D	σ_D	p	D	σ_D	p
I–II	+140	(751)	.46	+0.21	(.19)	.14	+0.15	(.82)	.42
I–III	+1020	(823)	.12	−0.22	(.16)	.10	+1.85	(.80)	.02
II–III	+880	(778)	.14	−0.43	(.19)	.02	+2.00	(.83)	.01

In Table V, the differences between Groups I, II, and III in magnitude, latency, and frequency of GSR to the tone alone after conditioning to the light are given. None of the magnitude differences are reliable ones. There is no reliable difference in latency between Groups I and II, nor between Groups I and III, but Group III shows a reliably longer latency than does Group II. There is no reliable difference in frequency between Groups I and II, but both Groups I and II show a reliably greater frequency of response than that shown by Group III. There is no evidence of a sensory conditioning having occurred in the subjects of Group I when the tone and the light were presented together prior to the conditioning of the GSR to the light. Since there are no reliable differences in the responses to tone alone between Groups I and II, the GSR to tone made by the subjects of Group I is a function of sensory generalization. The responses made by the subjects of Group III are also a function of sensory generalization, but since the latency of response of this group is reliably longer than that of Group II, and the frequency of response is reliably less than that of both Groups I and II, it follows that presentation of the tone alone prior to conditioning of the GSR to light inhibits sensory generalization of the CR to the tone. This decrement in generalization shown by Group III is clearly evident with regard to frequency, is probably true with respect to latency (the difference between Groups I and III has a p value of .10), but is unreliable as far as magnitude is concerned.[4]

[4] It might be thought that although no evidence of sensory conditioning is obtained when the 10 trials of tone alone after conditioning are compared in Groups I, II and III, positive evidence

The group means of the GSR to the extinction trials of light alone are given in terms of magnitude, latency, and frequency for each of the four groups in Table I. If there was an occurrence of sensory conditioning when the tone and light were presented together to the subjects of Group I, one might expect that the presentation of the tone alone after conditioning of the GSR to light would result in significantly greater extinction on the part of Group I than that shown by Groups II and III. The degree of extinction shown by the subjects of Group IV would then serve as the norm to which the other groups are compared. From Table VI, in which the differences

TABLE VI

DIFFERENCES IN GSR DURING EXTINCTION

The numerals in the left hand column refer to the different groups in the experiment. The figures in the columns headed by 'D' are differences between the means of the groups compared. The standard errors of the differences are given in the columns with 'σ_D' at the top. In the columns headed by 'p' are given the probabilities that such differences might be expected to occur when 100 samples are drawn at random from a homogeneous population.

Groups	Magnitude			Latency			Frequency		
	D	σ_D	p	D	σ_D	p	D	σ_D	p
I–II	+590	(892)	.25	+0.08	(.18)	.33	−0.15	(.92)	.44
I–III	+600	(705)	.20	+0.03	(.19)	.44	+0.30	(.98)	.38
I–IV	−290	(741)	.36	+0.46	(.18)	.01	−1.75	(.86)	.02
II–III	+10	(827)	.50	−0.05	(.21)	.40	+0.45	(.98)	.32
II–IV	−880	(858)	.16	+0.38	(.20)	.03	−1.60	(.87)	.03
III–IV	−890	(662)	.10	+0.43	(.21)	.02	−2.05	(.89)	.01

during extinction are given for each pairing of the four groups, it is evident that the response of Group I during extinction does not differ significantly from that of either Groups II or III. All differences between these groups, for magnitude, latency, and frequency, have p values greater than .05. Nor is there any reliable difference in the magnitude, latency, or frequency of response made by Groups II and III. Group IV, on the other hand, shows a reliably shorter latency and a reliably greater frequency of response than either Group I, Group II, or Group III, but there is no reliable difference in the magnitude of response from that of any of these groups. The giving of 10 trials of tone alone after conditioning results in a significantly greater extinction in terms of latency and frequency of response, but not magnitude, which is independent of the events

would be obtained by comparing either the first 5 trials of tone alone, or the last 5 trials of tone alone. These comparisons were made, but since the results were similar to those obtained by comparing all 10 trials, these data are not presented. A breakdown of the results of the extinction trials to light alone in like manner gave results no different from those obtained when all 10 extinction trials were used.

preceding conditioning. Since the evidence of greater conditioning of Group IV is confined to magnitude with some differences in latency, the above conclusion is valid.

The verbal reports of the subjects were entirely consonant with the results obtained from the objective records. Approximately the same number of subjects from each group defined the experiment as one on conditioning. There were 12 such subjects in Group I, 9 in Group II, 11 in Group III, and 13 in Group IV. Of these, 2 in Group I, 2 in Group II, 1 in Group III, and 3 in Group IV were able to name correctly the response being conditioned. Application of the χ^2 test of independence (4) to these frequencies reveal that none of the groups are differentiated from each other. When the members of Groups I, II, and III were asked if they expected to receive shock with the tone when it was given immediately after the conditioning trials, 9 subjects in Group I, 12 in Group II, and 3 in Group III answered affirmatively. When the χ^2 test of independence is applied to these frequencies, it is found that Groups I and II, and Groups I and III are not independent, whereas Groups II and III are independent. This agrees with the finding that there was less sensory generalization with Group III than with Groups I and II. Those subjects who said they expected shock with the tone, consistently gave as the reason for their expectancy that they had received shock with the light. Only one subject in Group I gave the pairing of the tone and light prior to conditioning as the reason for expecting shock with the tone. None of the subjects in Group I reported that the glass plate was illuminated when the tone was given after conditioning. There is no evidence of a conditioned synesthesia. During the extinction trials, 17 subjects in Group I, 18 subjects in Group II, 19 subjects in Group III, and all of the 20 subjects in Group IV reported that they expected to receive shock. Although none of the groups are independent of each other as shown by the χ^2 test, the greater number of subjects expecting shock during extinction in Group IV than in Groups I, II, or III fits the finding of less extinction with the subjects of Group IV than with those of Groups I, II, or III.

The data were broken down for sex and for the spatial location of the tone and the light in the stimulus-box. No sex differences were present. The results were also the same no matter whether the loud speaker was to the left of the light or whether the light was to the left of the loud speaker.

Discussion

The failure to obtain sensory pre-conditioning in the present experiment and the demonstration of this phenomenon in the earlier

study with dogs (1) must be a function of the differences in the experimental conditions of the two investigations. The two experiments differed from each other in a number of ways, and any one of these differences or combinations of these differences might be the responsible factor or factors in determining sensory pre-conditioning. First, there is the obvious difference in the subjects used in the two experiments; in the one case, human beings were used as subjects, whereas in the other, dogs served as the subjects. Second, there were only 10 sensory conditioning trials in this experiment, where there were 200 in the other. Third, conditioning in the present experiment was not as well established; only 25 conditioning trials were given. In the experiment with dogs, all subjects were conditioned to a criterion of 20 CR's in one test-period of 20 trials. This criterion was reached only after from 200 to 360 training trials. Fourth, the tests of sensory-pre-conditioning were not as extensive in the experiment with human subjects. Only 10 trials of the tone alone were given after conditioning of the GSR to the light. In the experiment with dogs, the stimulus that had never been paired with shock was presented in series of 20 until no CR's were obtained in 20 trials. Fifth, the GSR was used as the UR in this experiment. It was elicited by both the tone and the light prior to training, and showed a great deal of variability in magnitude, frequency, and latency under all the conditions in which it was evoked. Forelimb flexion, the UR in the other experiment, was not evoked by either the bell or the light prior to training. Sixth, classical conditioning training was used in the present experiment, whereas instrumental conditioning was utilized in the original experiment. Only further experimental work can demonstrate whether sensory pre-conditioning occurs with human subjects, and what the factors are upon which this phenomenon is dependent.

Positive evidence, however, was obtained upon two points in this experiment. The presentation of 10 trials of tone alone, prior to the conditioning of the GSR to light, reduces the degree of sensory generalization to tone after conditioning. Fewer subjects expected shock with the tone who were given this procedure than those in Groups I and II. It was also demonstrated that the presentation of 10 trials of tone alone following conditioning of the GSR to light, produced greater extinction of this response to light than that which occurs immediately following conditioning. This was true no matter whether pre-training was given prior to conditioning, and no matter what kind of pre-training was given before conditioning. The verbal reports of the subjects concerning their expectancy of shock during extinction bear out this finding, although there were no

reliable differences in the frequency with which the different groups expected shock in the extinction trials.

Summary of Conclusions

1. The GSR to tone of human subjects who were first given 10 trials of tone and light together and then 25 conditioning trials of light and shock cannot be differentiated from that given to tone by subjects who were first given only the 25 conditioning trials of light and shock. There is, therefore, no evidence of sensory pre-conditioning. The concept of sensory generalization adequately accounts for the behavior of both groups of subjects.

2. Comparison of the GSR's of these two groups during 10 extinction trials of the light alone after the 10 trials of tone alone gives confirmation to the above conclusion.

3. The GSR's to tone alone of subjects who were first given 10 trials of tone alone and then 25 conditioning trials of light and shock are reliably longer in latency and reliably less in frequency than that of subjects who were given only the 25 conditioning trials; they are of reliably less frequency than the responses to tone of subjects who were first given 10 trials of tone and light, and then 25 conditioning trials of light and shock. It follows that the presentation of 10 trials of tone alone prior to conditioning inhibits sensory generalization to the tone alone after conditioning.

4. Evidence of greater extinction during the trials of light alone was obtained for the three groups of subjects who received 10 trials of tone alone between the conditioning and extinction trials than for a group of subjects who were extinguished immediately after having been conditioned. The greater degree of extinction of these three groups was independent of whether there was pre-training before conditioning and of the kind of pre-training before conditioning.

5. Verbal reports by the subjects, appropriate to that one of the four groups to which they belonged, on the nature of the experiment, the expectancy of shock to tone alone after conditioning, the expectancy of shock to light during extinction, why they expected shock in these conditions, and on synesthesia were in agreement with their behavior as indicated by their GSR's in the respective experimental procedures.

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SOME FACTORS RELATED TO PSEUDO-CONDITIONING[1]

BY DELOS D. WICKENS AND CAROL D. WICKENS

University of Wisconsin

Introduction.—The purpose of the present experiment was to determine whether some of the principles of Pavlovian conditioning may also be operating in the process which has been called pseudo-conditioning.

If a series of fairly strong unconditioned stimuli is presented alone and that series is followed by a previously neutral stimulus, it is found that this previously neutral stimulus now produces a response similar to the one given to the unconditioned stimulus—this, although the two stimuli have never been paired. This phenomenon, now called pseudo-conditioning, first was observed as the result of controls which were run in some typical conditioning experiments (**1**, **10**, **11**, **12**, **13**, **14**, **15**). That such a modification of behavior could occur through the mere presentation of the unconditioned stimulus alone was obviously significant in the interpretation and evaluation of most conditioning experiments. Despite this fact, only an occasional investigator in the field of conditioning employed this control. The term pseudo-conditioning was not applied until 1938, when Grether (**4**) observed the phenomenon in experiments with monkeys, named it, and pointed out its importance. Since that time, there have been a few studies directed specifically towards determining the functional characteristics of pseudo-conditioning itself (**2**, **3**, **5**, **6**, **7**, **8**, **9**).

Several interpretations of pseudo-conditioning have been offered, all of them being at a definitely speculative level.

One hypothesis advanced by Sears (**10**) and supported by Harlow (**5**), is couched in neurological terms and assumes that the phenomenon of pseudo-conditioning is a cortical dominant, brought about, in this case, by external stimulation rather than by the hormal or visceral afferent stimulation to which the dominant is usually attributed. No experimental evidence is offered as crucial support for this theory, nor does the experiment herein reported either support or refute it.

A second interpretation of pseudo-conditioning assumes that the repeated presentation of the unconditioned stimulus develops an 'attitude of expectancy' in the organism (**4**, **6**). Once this attitude of expectancy has been established, and apparently *because* the

[1] This work was conducted in the Psychological Laboratory of Oberlin College.

attitude of expectancy has been established, the organism will respond to other stimuli with the same response—or nearly the same response—that it has been making to the unconditioned stimulus. Grant's description of pseudo-conditioning as growing out of a 'generalized set to respond' (**2, 3**) appears to be similar to the above mentioned attitude of expectancy hypothesis. All investigators who have proposed the expectancy interpretation, or some variant of it, view pseudo-conditioning as essentially non-associative in nature in contra-distinction to Pavlovian conditioning which assumes an associative or contiguity factor.

Another interpretation of pseudo-conditioning suggested itself to the writers in connection with an experiment on neonates (**15**) in which both conditioning and pseudo-conditioning were observed. It appeared possible that pseudo-conditioning might actually be true conditioning with associative or contiguity factors present. The organism might be responding to the pseudo-conditioned stimulus by virtue of the fact that this pseudo-stimulus actually had some characteristic in common with the unconditioned stimulus and that this characteristic necessarily was present at the time of the response to the unconditioned stimulus. The common characteristic serves, then as a conditioned stimulus. Such an interpretation as this demands first that we consider that any physical disturbances may be a complex of stimuli for the organism, and, second, that we grant that two very dissimilar complexes of stimuli yet may have some similar aspects. Shock, a possible unconditioned stimulus in a pseudo-conditioning experiment, and buzzer, a possible pseudo-conditioned stimulus, seem to be two very dissimilar stimulus complexes, yet they may have something in common. Although one is auditory and the other nociceptive, they are both changes in the environment, and they both may have similar rate of change. They both may have a certain characteristic of suddenness or a certain characteristic of gradualness. Hence, in the pseudo-conditioning situation, the organism may respond to the buzzer as it does to the shock, because those two stimulus complexes actually do have something in common. It is not implied that rate of change is the only characteristic which an unconditioned stimulus and a pseudo-conditioned stimulus may have in common. Rate of change was simply selected as a working example which seemed applicable to many of the existing experiments on pseudo-conditioning. The common characteristic, or conditioned stimulus, might also be a cutaneous similarity between the two stimuli, or a similarity of the external environments, or any one of a number of similarities. The essential condition is simply that there be a common characteristic which makes a contiguity factor able to operate.

To test the validity of the last mentioned hypothesis, the present experiment was planned. Four different pseudo-conditioning situations were set up, so designed that the attitude of expectancy interpretation should be equally or nearly equally applicable to each situation. However, the opportunity for the operation of associative factors (through the presence of similar aspects in both the unconditioned and the pseudo-conditioned stimulus) was greater in some groups than in others. If there were differing results, one might conclude that real associative factors were contributing to produce pseudo-conditioning.

Subjects.—The subjects used in the experiment were 37 albino and hooded rats of about 90 days of age. The animals had been handled once a day for at least a month before the experiment began and hence were well adjusted to the experimenter. Four groups were constructed by the split litter technique with albino and hooded rats, and the two sexes, occurring equally frequently in each group.

Apparatus.—In the experimental situation the animals could escape from shock by running from one to the other end of a partitioned, sound proofed box, when the grid underfoot was electrified. The box was rectangular in shape, its inside dimensions being 29 in. by 10 in. by 10 in. The four interior walls were composed of masonite, and the sound shielding was provided by surrounding these walls with two sheets of fiber board separated by an air gap. The box was covered by a double plate glass window. The entire floor was a grid, consisting of a series of 1/8 in. rods, spaced at 1/2 in. intervals. This grid was electrified by a high voltage power pack with high resistance in series. A masonite partition, extending down to within 3½ in. from the floor, divided the box into two equal compartments. Each compartment was illuminated by three number 48 Mazda two volt pilot light bulbs, which were electrified with a maximum of 1.7 volts. These were located nine inches from the floor at the middle of the end and the middle of the sides of each compartment. The stimuli were applied by the means of silent mercury switches on a control panel located several feet from the experimental box. It was possible to electrify the grid and the lights of one compartment independently of the other. Both the shock and the light controls were so constructed that either a *gradual* or a *sudden* shock or a gradual or a sudden light could be presented. (Thus the experimenter could control the rates of change of the stimuli.) The gradual nature of a stimulus was effected by means of a rheostat. As the experimenter slowly moved an arm along the rheostat, a gradual decrease of the resistance in the circuit was produced. The experimenter who operated this control checked the speed of the movement against a stop watch and maintained an interval of five seconds as the time which was required for the gradual stimulus to develop to its full intensity. The sudden stimulus, on the other hand, reached its maximum in something less than 1/10 of a second. The maximum value of both stimuli was, of course, the same.

The conditions of illumination in the box and the room were such that about five minutes dark adaptation was required for the experimenters to discern the shape and movement of the animals on the grid.

Procedure.—In general, the procedure was typical of any pseudo-conditioning control group, consisting of the administration of a series of unconditioned stimuli, then a test for response to the neutral stimulus. For each rat the experiment continued over four days. On the first day, the animal was placed in the box and allowed a five minute period for exploration and adaptation. Following this, the light or pseudo-conditioned stimulus was presented three times. If any animal crossed to the other compartment during the five second period during which the light was on, it was excluded from the experiment. Crossing here, as in the later parts of the experiment, was considered to have occurred only when the animal entered the other compartment with as much as 3/4 of his body. Four animals out of 41 were eliminated because of such original response to the light. The remaining 37 passed on to the next step of that day's procedure, which consisted of the presentation of 10 shocks alone (the unconditioned stimulus). On the second day, the rat received 15 shocks, and on the third day, 10. Thus, there were administered, over a period of three days, 35 shocks alone which were never paired with the light. These shocks were presented at intervals of 30, 60, or 90 seconds in a prearranged irregular pattern. Responses to

each stimulation were always recorded. (It was found that, after a short learning period, the animal's characteristic response to shock was to cross quickly to the other compartment.) At the end of the 3rd day, the light, or pseudo-conditioned stimulus, was again given until there were three consecutive failures to respond. The response to light, or pseudo-conditioned response, of course consisted in the animal's leaving one compartment within the 5 seconds during which the light was on. All animals were tested for spontaneous recovery on the 4th day, the same criterion of extinction, three consecutive failures to respond, being used.

As indicated above, the design of the experiment demanded the formation of four groups of animals. The composition of the groups is given in Table I. Group 1 received 35 *sudden* shocks

TABLE I

THE COMPOSITION OF THE VARIOUS GROUPS IN TERMS OF THE RATE OF CHANGE OF THE UNCONDITIONED AND THE PSEUDO-CONDITIONED STIMULUS

Groups	Rate of Change	
	Shock	Light
1. Experimental	Sudden	Sudden
2. Experimental	Gradual	Gradual
3. Control	Sudden	Gradual
4. Control	Gradual	Sudden

as its unconditioned stimulus, and then was tested to a *sudden* light. Group 2 received 35 *gradual* shocks and was tested to a *gradual* light. These two groups are the experimental groups. Although the pseudo-conditioned stimulus and the unconditioned stimulus are in different sense modalities, they also have a common characteristic—that of similar rates of change within each group. On the other hand, the control groups, groups 3 and 4 in the table, were designed so that the unconditioned stimulus and the pseudo-conditioned stimulus differ both in sensory quality and in rate of change. Thus, group 3 was given 35 *sudden* shocks and was tested to a *gradual* light; while group 4 received training on *gradual* shocks and was tested to a *sudden* light. There was, then, far less similarity between the unconditioned stimulus and the pseudo-conditioned stimulus in these control groups than in the experimental groups in which the character of the change of the stimulus was the same.

The above procedure was so designed as to imply a prediction. If pseudo-conditioning includes some associative factor, we would predict that the experimental groups would show significantly more pseudo-conditioned responses than the control groups. A theory which holds that pseudo-conditioning is solely due to an attitude of expectancy would, we believe, predict a nearly equal distribution of pseudo-conditioned responses in the four groups.

Results.—The results are presented in terms of the number of animals in each group responding to the pseudo-conditioned stimulus on either the third or the fourth day. (Actually, most animals who responded on one day, also responded on the other.) These results are given in Table II. Group 1 was the experimental group which was given a sudden shock and tested to a sudden light. Of the nine animals in this group, seven gave pseudo-conditioned responses. In group 2, the other experimental group, the rate of change for both stimuli was gradual, and eight out of the ten animals in that group responded to the light alone. In group 3, the control in which the stimuli, a sudden shock and a gradual light, were different, only one animal in nine responded to the pseudo-conditioned stimulus. Group 4, the control group whose unconditioned stimulus of a gradual shock was also different from the pseudo-conditioned stimulus of a sudden light, was composed of nine animals. Only two of these nine

TABLE II

THE NUMBER OF ANIMALS IN EACH GROUP WHO RESPONDED TO THE PSEUDO-CONDITIONED STIMULUS

Groups	Number of Animals		
	Total	Responding	Not Responding
1. S-S (exp.)	9	7	2
2. G-G (exp.)	10	8	2
3. S-G (con.)	9	1	8
4. G-S (con.)	9	2	7
Total experimental	19	15	4
Total control	18	3	15

responded to the light. The fifth row of the table gives the combined results for the two experimental groups. Fifteen out of the 19 animals responded to the light and four did not. In a similar fashion, the sixth row gives the results for the two control groups combined. Here, it is found that only three out of the 18 animals responded to their pseudo-conditioned stimulus.

It is apparent from an examination of this table that there is a considerable difference between the behavior of the control and the experimental animals. The question now arises as to whether this is a true difference or a difference attributable to errors in sampling.

Each group was compared with each other group by the chi squared technique. These calculations are given in Table III. In

TABLE III

A COMPARISON OF THE RESULTS OF THE VARIOUS GROUPS IN TERMS OF CHI SQUARED AND PROBABILITY VALUES

Groups	χ^2	*P* value
S-S vs. G-S	5.555	.02
S-S vs. S-G	8.100	.01
G-G vs. G-S	6.357	.02
G-G vs. S-G	8.999	.01
G-G vs. S-S	.011	.90
G-S vs. S-G	.399	.60
Exp. vs. con.	11.733	.01

column one, the groups being compared are indicated, while column two gives the chi squared value for that comparison, and column three the probability of no difference for a chi squared of that value with one degree of freedom. Summarizing briefly, we can see that between any one of the experimental groups and any one of the control groups there is a statistically significant difference—that is, the probability of no difference is less than .02, and any hypothesis that no difference exists may best be rejected. However, when we com-

pare one experimental group with the other experimental group we find a different situation, the probability that no difference exists being .90, and, when we compare one control group with another control group, the probability of no difference is .60. Both of these values are high and clearly indicate that the two control groups are essentially alike. A final comparison is one between the total experimental group and the total control group. When this comparison is made, a chi squared value of 11.733 is obtained, which means that there is considerably less than one chance in 100 that these two groups are alike. It appears, then, that there is a very real difference between the results for the experimental groups and those for the control groups.

Since statistical treatment has indicated that the obtained differences are real ones, it becomes pertinent to reëxamine the experiment to determine whether the obtained differences are due to the defined variable or to some possible artifacts of the experiment.

If the animals of one group were in some way essentially dissimilar to the animals of another group, this dissimilarity might produce the difference obtained. It is, however, not at all likely that this was true in the present experiment. It will be recalled that the composition of all four groups was similar in terms of age, sex, and pigmentation.

If the animals had been receiving cues from the apparatus or the experimenter, this could have distorted the experimental results, though it is difficult to see why the distortion would have been in one direction only. In order to check on this, dummy trials were interspersed throughout the experiment. In these trials the circuit to the box was broken and switches were operated just as if stimulation were to be given. These control trials were uniformly negative.

If the animals had been very restless under their shock training and had continually run back and forth between the two compartments, this too would have been a source of error in that responses would have been recorded simply because the animal happened to be crossing at the time the pseudo-conditioned stimulus was presented. Here again, the error would have been committed equally in all four groups and the differing results should not have been obtained. Such a possibility has been suggested to the authors, however, and it seems worth while to state that restlessness was not at all typical of the animals' behavior either during or after shock treatment. Characteristically, the animals would cross to the other compartment after the shock stimulation and crouch there, motionless and tense. Usually, they took up a position in the middle of the compartment with their heads pointed toward the other compartment.

It appears, then, that we are justified in assuming that the obtained differences may be due to the designed variable in the experiment and not to artifacts.

Discussion.—It will be recalled that three differing interpretations of pseudo-conditioning were presented in the introduction to this paper. The theory that pseudo-conditioning is a cortical dominant does not seem to have been developed to a predictive level, capable of experimental verification, and the data of this experiment in no way bear upon it. We believe, however, that the hypothesis that pseudo-conditioning arises from an 'attitude of expectancy' can be used for predictive purposes, and further, we believe that such an hypothesis would have failed in any prediction of the results of this experiment. The theory of an attitude of expectancy, as it has been stated in the literature, could not have allowed for the differences which existed between the results of our experimental and the results of our control animals. Both groups of animals received an unconditioned stimulus, and a pseudo-conditioned stimulus, and this combination, if capable of producing pseudo-conditioning in any group, should have produced it in all. It is possible, of course, that the expectancy hypothesis might be modified to predict our results, by stating that the attitude of expectancy is more apt to be aroused by a pseudo-conditioned stimulus which is similar to the unconditioned stimulus than by one which is not. When this is done, however, the possibility for the operation of associative factors is immediately present, and proponents of the theory have specifically denied the operation of associative factors in pseudo-conditioning. This necessary modification also tends further to complicate an interpretation which already stands at a complicated and highly inferential level.

The final hypothesis (the one advanced by the authors) postulated that pseudo-conditioning was actually a form of Pavlovian conditioning and that the organism was responding to the pseudo-conditioned stimulus by virtue of the fact that the pseudo-conditioned stimulus actually had some characteristic in common with the unconditioned stimulus. In this particular experiment, the common characteristic, or conditioned stimulus, was the rate of change of the stimulus. In the groups where the rate of change of the pseudo-conditioned stimulus and the unconditioned stimulus was similar, there was a high degree of conditioning, or, if you will, pseudo-conditioning. In the groups in which there was a differing rate of change for the pseudo-conditioned and the unconditioned stimuli, the amount of conditioning was slight. Thus, the kind of rate of change which occurred along with the running response produced by the shock was the kind of rate of change characteristic of the effective, but not of the ineffective, pseudo-conditioned stimulus. This is what one would expect from conditioning theory. Thus, pseudo-conditioning may be

a special case of stimulus generalization in which the organism fails to discriminate important differences between stimuli and reacts only to their similarities. At first glance, this hypothesis may seem to be a complicated one, but the writers feel that a closer examination of it shows it not to be so. A consideration of several of the basic premises in the hypothesis may make this clear. First, there is the premise that organisms will learn and that this learning is frequently accomplished through the occurrence together in time of several stimuli, followed by a response or responses to one of these. The learning consists of the modification of the response to at least one of the stimuli. This is merely Pavlovian conditioning. Next, it is implied that other stimuli similar to this stimulus will also provoke this modified response. This is stimulus generalization. Finally, we make an assumption as to what makes for similarity or non-discriminability. The hypothesis asks that we accept as a cue for similarity not only unimodal stimulation, but also heteromodal stimulation, which is alike in some controllable physical aspect.

The hypothesis, it should be noted, would still admit that non-associative factors may operate in the pseudo-conditioning situation. It would permit and expect that such factors as degree of tension, alertness, motivational states, and other factors, may contribute toward responsiveness, just as they may in the typical conditioning situation.

Although such evidence is necessarily indirect, it seems worth while, in any consideration of pseudo-conditioning as true conditioning, to mention the fact that the phenomena of pseudo-conditioning so often parallel the phenomena of true conditioning. Extinction of the pseudo-conditioned response has been found in several experiments (**6**, **7**, **13**, **14**, **15**). Spontaneous recovery has been reported also (**6**, **15**). Switzer (**13**) has noted disinhibition of pseudo-conditioned responses, while Grant and Dittmer (**2**) have presented evidence for stimulus generalization in pseudo-conditioning. It is apparent that the last mentioned hypothesis, using what knowledge we now have of the generalized conditioned response, would have predicted the trend of events in all the above experiments. It is also true that it could have predicted all of the positive results obtained in the various pseudo-conditioning experiments which have been done, in view of the fact that, in these experiments, there was always some element in common between the pseudo-conditioned stimulus and the unconditioned stimulus.

Summary

The present experiment was undertaken to determine whether the Pavlovian principle of stimulus generalization could be contributing to the phenomenon of pseudo-conditioning. Four experimental situa-

tions were set up in such a way that in two situations there was opportunity for generalization to operate, and in two situations there was little or no opportunity for its operation.

White rats escaped shock by running from one to the other end of a partitioned box when the grid underfoot was electrified. Following 35 shocks alone a light was flashed on in the occupied compartment. Pseudo-conditioning consisted of leaving the compartment in response to the light stimulus.

Four groups of rats were used. For one, the shock occurred suddenly and the light occurred suddenly; for the second, both shock and light built up gradually; for the third, the shock was sudden and the light gradual; for the fourth, the shock was gradual and the light sudden.

The results show a high degree of pseudo-conditioning in the first two groups, and almost none in the last two groups. These results are consistent with the hypothesis that pseudo-conditioning may be akin to Pavlovian stimulus generalization, and is not in accord with the hypothesis that pseudo-conditioning arises from an attitude of expectancy.

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INDIVIDUAL DIFFERENCES IN PHYSIOLOGICAL REACTIONS TO STIMULATION AND THEIR RELATION TO OTHER MEASURES OF EMOTIONALITY

BY G. L. FREEMAN AND E. T. KATZOFF

Northwestern University *

The relationship of physiological reactions to the more conventional measures of emotionality (questionnaire tests, psychiatric diagnoses, etc.) has not been extensively explored.[1] Darrow and Heath (**2**) studied the blood pressure and skin resistance changes produced by ideational and sensory stimulation in relation to certain items of the Northwestern Extroversion-Introversion tests and the Thurstone Neurotic Inventory. They reported as follows:

> There is evidence that physiological reactions under certain specified conditions and certain personality traits, as revealed by the questionnaires, show a concommitant variation. . . . The galvanic recovery-reaction quotient (percent recovery during three seconds after the peak of reaction) . . . appears to be one of the better indicators of the absence of neurotic tendencies.

Darrow and Heath suggest that the correlation of physiological reactions with other measures of emotionality will take on more significance as the stability of physiological measures and the validity of personality tests are established.

Since this pioneer report, several studies utilizing physiological measures have dealt with limited aspects of the problem. Duffy (**3**), Freeman and Katzoff (**7**) and Luria (**11**) have reported various measures of muscular tension as related to 'emotionality,' 'irritability,' and 'disorientation.' Wenger (**12, 13**) made a large number of static physiological measures (basal metabolic rate, resting level of galvanic skin resistance, etc.) together with ratings of emotionality. He subjected his results to a factorial analysis, reporting the presence of a 'tension' factor and others not as clearly defined. In another study, Wenger (**14**) found that individual differences in measures of 'autonomic' balance were distributed continuously about a central tendency. Mention should also be made of the work by Darrow and Solomon (**2a**) on the use of skin resistance measures in diagnosing

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[1] There have been, of course, a large number of studies in which physiological reactions have been recorded during emotional stimulation. However, little attempt has been made to relate individual differences in such reactions to other measures of emotionality. The usual pattern of physiological research in emotion has been to survey the characteristic of the typical response made to a given situation. (*Cf.* Landis & Hunt (**10**) on the startle pattern.)

emotional difficulties of psychotic patients. Individual differences in skin resistance changes before, during, and after experimentally sustained physiological (bladder) tension were studied by Freeman (**5**); the close correspondence of 'physiological recovery quotients' obtained under a variety of experimentally produced disturbances was reported in a later paper by the same author (**6**). This later report dealt with only ten cases, and while suggestive of a fruitful technique for the study of individual differences in emotionality, did not yield data sufficient to warrant specific conclusions. The present study is an extension of the use of physiological measures to a wider variety of experimental stimulations and a somewhat larger population.

Experimental Procedures

Twenty-four college men served as *S*s in the experiment. Galvanic skin resistance changes [2] were obtained for all *S*s under four different types of experimental stimulation. *S*s lay on a pneumatic mattress, by means of which gross (restless) movements were recorded mechanically. Additional quantitative measures (reaction time and voice level intensity) were obtained in certain tests. At the beginning of each experimental session *S* rested until his 'basal' resistance level showed stability.[3] He was then given controlled 'test' stimulation and following its cessation was carried through a 'post test' observation of five min. duration. The experimental stimulations are described below.

Test 1, Startle.—The stimulus was a .22 cal. blank cartridge fired out of *S*'s line of vision and without warning.

Test 2, Motor Conflict.—*S* was instructed to push 'right' or 'left' keys with the index finger as signaled by a 'right' or 'left' stimulus light. Wrong or delayed responses were punished by electric shock delivered through the reaction key. The series began with five trials in which either the right or left light was flashed; then followed 20 trials of which ten (in random order) were conflict situations—*i.e.*, both lights flashed simultaneously with shock punishment for all possible reactions. Finally, five more trials were given in which no double (conflict) stimulation was given. The entire test took seven min. Reaction time was recorded throughout.

Test 3, Verbal Association.—After *S* was relaxed to the 'basal' state, instructions calculated to reinforce existing personal conflicts were read. *S* then responded to a series of stimulus words, some of which were non-critical (such as 'chair'), and some of which were critical (such as 'masturbation'[4]). The critical words were those on which blocking by an acquired inhibition or restraint might reasonably be expected.[4] The entire test, including the reading of instructions, took 18 min.

Test 4, Sensory Discrimination.—*S* was instructed to make a series of pitch discriminations.[5] The test began with ten easily discriminable pairs of tones, passed to discriminations of increasing difficulty, and then returned to the first ten 'easy' discrimination pairs for a recheck. During the 40 interpolated pairs of stimuli, discriminations were made more difficult by introducing a distraction (intermittent ringing of telephone bell). The test took seven min. to complete.

Each of the above situations was repeated on every *S*. Two different situations appeared in a single experimental session, but since these were properly counterbalanced the effect of presentation order is not discussed in this report.[6] The repetitions of a given situation upon an *S*

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[2] The Behavior Research Resistance box (Darrow) was used. Zinc sulphate electrodes were attached to each palm of *S*.

[3] This was arbitrarily defined as no fluctuation in excess of 1000 ohms in five min.

[4] Since we are not here interested in the specific word responses given, these are not discussed in this report. For a complete description of instructions of this and other tests, *cf.* Katzoff, E. T., *Statistical Analysis of Individual Differences Involved in Reactions to Experimental Stimulation*, Ph.D. thesis (unpublished), Northwestern University Library, 1941.

[5] Record 1A of the *Seashore Musical Talent Test* was used.

[6] Variability resulting from order of presentation was subjected to an analysis of variance. For results *cf.* Katzoff, E. T. Unpublished Ph.D. thesis, Northwestern University Library, 1941.

were separated by an interval ranging from one day to a month. The entire experiment ran from November 1939 to May 1940.

Other Tests.—In addition to taking the four tests previously described, each subject answered 100 questions designed to expose differences in such emotional 'traits' as 'general neuroticism,' 'drive,' 'anxiety,' 'lack of control,' 'visceral lability,' and 'response variability.' These items were selected from standardized personality tests [7] and were mostly of known discriminating value. The *S*s also rated themselves on a five point continuum on each of 18 behavioral aspects of 'emotionality,' such as: "Are you emotionally calm or excitable?" They were interviewed by Dr. Leon Saul of the Institute of Psychoanalysis and the senior author, then ranked for emotional stability. Time samples of nervous movements were obtained.

Derivation of Variables

Many previous studies of the relation of physiological reactions to the emotional aspects of behavior have been inconclusive, due to the choice of variables to be employed. Dunbar (**4**, p. 100), commenting on the absence of significant work in this field, states:

". . . Our most satisfactory measurements are those that can be expressed in terms of the 'second derivative,' . . . the most satisfactory data are obtained by taking simultaneously the curve of a series of physiological reactions rather than any one alone."

Dynamic studies of personality interrelations require the use of derived variables. This is indicated by the fact that the most significant physiological measures of emotionality previously reported [Darrow and Heath (**2**), Schneider and Freeman (**6**)] have been those of rates or ratios of change.

The measures of galvanic skin resistance taken at one min. intervals during the experimental sessions may be given any one of several expressions. Our derived measures, C.I. (percent conductance increment under stimulation) and C.R.Q. (percent recovery of original conductance at five min. following cessation of stimulation), have received theoretical and empirical justification in a previous report (**8a**). For present purposes, it is sufficient to summarize the procedure under which these and related variables were derived.

C.I. (*Conductance Increment*).—The resting conductance level prior to stimulation is used as a base 'A' and the level one minute after stimulation is taken as a 'test' response 'B.' Percent conductance increment, or galvanic arousal, equals $(B-A)/A$.

C.R.Q. (*Conductance Recovery Quotient*).—The conductance level five min. after cessation of stimulation [8] is taken as a post-test response 'C,' and percent recovery equals $(B-C)/A$. Conductance R.Q. is the ratio of percent increment to percent recovery; but since both percentages rest upon the same base 'A,' the formula for C.R.Q. reduces to $(B-C)/(B-A)$.

M.I. (*Movement Increment*).—In addition to the covert measures indicated above, changes in the amount of gross movement resulting from each of the four situations were obtained. Since a 'movement basal' was recorded in each situation, it was possible to express the amount of movement which followed the stimulus as a percentage increment.[9]

R.T.R.Q. (*Reaction Time Recovery Quotient*).—Reaction times for pre-critical, critical, and post-critical associations were recorded in the verbal test. The average of pre-critical reaction times supplied a 'basal' analogous to point 'A' in the galvanic response curve. Similarly, critical reaction time averages yielded a 'B' point, and the post-critical reaction time averages a 'C' point. Thus by the formula employed above for C.R.Q., a reaction time R.Q. was computed.

V.L.C. (*Voice Level Change*).—Due to the fact that the voice level was frequently lowered to the point of a whisper in the case of critical words, there was no reason to compute voice level increment. Consequently, voice level *change* in either direction from a pre-test 'basal' was the measure employed.

V.L.R.Q. (*Voice Level Recovery Quotient*).—Even in cases where the voice level was lowered in response to critical words, recovery of level occurred in post-critical associations. It was thus

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[7] Questions were selected from Guilford's and Thurstone's Personality schedules and the Northwestern E-I test.

[8] The experiment included both momentary and sustained stimulation, but no distinction is made with respect to this factor. The choice of a five min. recovery interval is arbitrary. The point 'B' was near the peak reaction of galvanic response curve.

[9] Due to the latency of stimulus-produced motor discharge M.R.Q. measures were found to be invalid (after the formula for C.R.Q.) and are not here included.

possible to compute an R.Q. in terms of return to basal from either direction of critical word change.

M.B.C. (*Mean Basal Conductance*).—Since each *S* rested until his palmar conductance became stable [10] it was possible to compute a mean level at which the stabilization occurred in each subject. This measure was taken as an index of the general level of physiological activity.[11]

B.C.V. (*Basal Conductance Variability*).—As a measure of the variability of the level at which skin conductance stabilized, the *range* of basal level for the several experimental periods was employed.

M.B.M. (*Mean Basal Movement*).—As in the case of the basal conductance level, the mean amount of pre-test movement was recorded.

B.M.V. (*Basal Movement Variability*).—Variability in basal movement was derived by taking the *range* for the several experimental sessions as in the case of conductance.

Results

Thirty variables were subjected to factor analysis. Of these, 10 were measures of covert physiological activity, 11 were measures of overt behavior, and 9 were ratings and personality tests. These variables, together with their final factor loadings, are presented in Table I. In preparation for the analysis of the data, each of the 24 Ss was ranked on each of the variables. The next step was to correlate each ranking with every other by the rank-difference method. These 435 correlations are presented in Table II.

TABLE I

Loadings on Orthogonal Axis after 10th Rotation

Variables	I	II	III	IV
1. Basal Conductance Variability (B.C.V.)	.11	.38	−.31	.04
2. Ave. Cond. Recovery Quotient startle (C.R.Q.)	.89	−.10	.05	.35
3. Ave. Cond. Recovery Quotient motor (C.R.Q.)	.55	.05	.13	−.16
4. Ave. Cond. Recovery Quotient verbal (C.R.Q.)	.75	−.01	.08	−.10
5. Ave. Cond. Recovery Quotient distraction (C.R.Q.)	.21	.73	.01	.12
6. Percent Cond. Increment startle (C.I.)	.10	.86	.06	.18
7. Percent Cond. Increment motor (C.I.)	.19	.86	.21	.10
8. Percent Cond. Increment verbal (C.I.)	.35	.58	−.03	−.12
9. Percent Cond. Increment distraction (C.I.)	.09	.90	−.06	−.20
10. Mean Basal Cond. (M.B.C.)	.00	.43	−.19	−.25
11. Variab. in Basal Movement (B.M.V.)	.62	.27	.50	.14
12. Movement Increment startle (M.I.)	.48	−.21	.06	.02
13. Movement Increment motor (M.I.)	.65	−.04	−.08	.06
14. Movement Increment verbal (M.I.)	.34	.25	−.20	.10
15. Movement Increment distraction (M.I.)	.49	.34	−.33	−.23
16. Mean Basal Movement (M.B.M.)	.73	.11	.25	−.15
17. Psychiat. rating	.57	.22	.30	−.15
18. Reaction Time verbal (R.T.)	−.08	.08	−.16	.72
19. Voice Level R.Q. verbal (V.L.R.Q.)	.61	−.14	.05	.41
20. Voice Level Change verbal (V.L.C.)	.38	.32	−.05	.32
21. Reaction Time R.Q. verbal (R.T.R.Q.)	.03	−.05	.03	.72
22. Behavior rating	.03	.03	.45	−.10
23. Reaction Time R.Q. motor (R.T.R.Q.)	.31	−.15	−.01	−.07
24. Time sample of nerv. movements	−.05	.07	.60	−.15
25. General neuroticism questions	.20	.00	.92	.08
26. Anxiety questions	.34	−.15	.68	.02
27. General drive questions	.08	.22	.33	.26
28. Inhibitory control questions	.31	.06	.58	.01
29. Visceral disturbance questions	.14	.03	.53	−.05
30. Variability questions	.02	−.24	.58	−.39

TABLE II

CORRELATION MATRIX. FOR IDENTIFICATION OF VARIABLES SEE TABLE I ABOVE.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
2.	10																													
3.	−45	34																												
4.	12	66	67																											
5.	−16	21	01	22																										
6.	−16	−14	−05	16	68																									
7.	−27	−44	03	−22	52	69																								
8.	−26	−12	34	38	27	68	48																							
9.	−21	−27	12	12	80	72	72	65																						
10.	65	31	−12	24	−27	−13	−36	−16	−38																					
11.	−12	−70	−15	−51	−45	−32	−15	−32	−29	04																				
12.	16	51	−09	08	02	−06	−15	−11	−11	05	−31																			
13.	−07	53	50	53	−02	25	−18	27	00	00	−33	43																		
14.	−04	36	11	40	45	33	04	17	31	19	−08	14	20																	
15.	−17	24	42	28	47	38	12	33	46	−20	−24	20	37	39																
16.	−01	−65	−19	−50	−26	−09	00	43	−10	06	68	−52	−32	−33	−46															
17.	01	41	34	49	25	19	09	30	40	−15	−64	20	40	02	43	−47														
18.	−12	05	−05	−20	08	23	15	02	15	17	02	−04	00	−09	−02	27	16													
19.	−13	55	42	41	03	−01	−22	17	−12	15	−14	34	38	−16	09	−34	60	30												
20.	−13	48	−10	61	36	36	10	35	24	−11	−35	05	31	19	10	−16	40	09	49											
21.	−05	−06	04	09	−09	−15	15	12	28	−23	17	04	−15	30	00	−02	03	07	−44	−09										
22.	−17	−03	04	−19	−06	03	18	08	00	−21	35	03	00	25	23	19	−23	00	−17	25	17									
23.	10	−38	06	−15	−20	−09	09	12	−21	12	43	−30	−01	−25	−19	32	−13	05	−15	−19	−09	−10								
24.	−06	07	−17	−21	−01	12	−08	13	−07	16	17	30	18	24	07	12	−44	29	−11	03	−19	36	−18							
25.	09	−31	−07	−11	−15	−21	−17	−03	05	−14	52	−21	−11	04	23	38	−20	18	−10	00	−11	27	12	36						
26.	−03	−43	−15	−10	00	02	06	12	17	−03	45	−29	−20	−01	02	38	−12	14	−17	13	−02	14	20	21	84					
27.	−06	15	14	−01	−18	−22	−54	−17	−36	10	02	14	27	−29	37	05	−09	−06	27	−23	−07	−12	04	00	−11	−31				
28.	−04	−19	−14	−13	−08	−28	−27	−23	08	−23	32	−38	−15	−16	12	42	−25	14	−20	−05	−11	18	06	31	80	55	16			
29.	−15	−19	−10	−25	12	−14	−07	−11	12	−17	36	−08	−14	−11	16	26	−16	05	−01	−10	00	−02	−03	45	69	59	00	16		
30.	60	−15	−16	−01	−02	00	−11	−15	−25	36	07	05	−15	−21	−14	−06	18	−24	−05	−34	21	−40	02	−29	−46	−48	−18	−32	−28	

* Decimal points have been omitted throughout this entire table.

The obvious question to be raised with respect to the use of the factorial method concerns the validity of the procedure with so limited a population. Usually the factorial method has been used only where the sample was considerably larger than the 24 cases of this experiment. There is, however, at least one study (Wenger, **12**) in which a factorial analysis was performed on an even smaller sample. Subsequent work with a larger sample by the same investigator (Wenger, **13**) seemed to verify the findings of his original study.

Thurstone's centroid method of factor analysis was used. Four factors were removed and rotated with orthogonal axis to simple structure. The loadings of the 30 variables on the rotated axis are presented in Table I. In order to maximalize the original correlation matrix, the reflection of 14 of the 30 variables was required. When these reflections were carried through the analysis, a positive manifold as well as simple structure was achieved. The highest negative loading after reflection is .39. Since the lowest correlation significant at the 1 percent level with an N of 24 cases is .515,[12] we are able to say that there are no significant negative loadings in the final factors.

In Table III the loadings greater than .50 are presented. It is from the examination of these loadings that we may attempt to identify the factors. In Factor I we see a predominance of R.Q. variables.[13] In addition, the psychiatric rating (*P.R.*) and the *inverse* ranks on pre-test movement (*M.B.M.*) and on variability in

[10] In several cases due to factors unrelated to this experiment (*i.e.*, temporary emotional upset due to impending school examination) the palmar skin conductance continued to fluctuate beyond the 1000 ohm limit set. If skin conductance gave no indication of becoming stable within half an hour, *S* was dismissed and told to return at a later date.

[11] Cf. G. L. Freeman and L. L. Griffin (**7**).

[12] This figure is given for product-moment r's. Since the sigma of rho is greater than that of r, the highest negative rho is surely not significant. *Cf.* E. G. Lindquist. *Statistical Analysis in Educational Research.* Cambridge: Riverside Press, 1940.

[13] It is significant to compare the results of our factorial analysis with those of Jost (Unpublished Ph.D thesis, University of Chicago, 1940), whose study is closely related to our own. Of a total of 52 measures employed by Jost to differentiate groups of normal and maladjusted children, 17 had a C.R. above 2.00 and 10 a C.R. above 2.70. Of these the galvanic skin response proved to be one of the most highly significant. A factorial analysis of the data was performed for the 18 cases in the experimental group. Three factors resulted. The first was heavily loaded with a rating of emotional stability, percent time 'alpha,' and 'basal' muscular tension. The author labels this a 'general emotionality' factor. The second factor has three significant loadings all concerned with increment of physiological measures during stimulation. Jost labeled this a 'central factor' since all loadings were reflections of physiological changes. The present writers are more inclined to call this an 'arousal factor' since all significant loadings concerned increment of physiological variables under stimulation. The third factor in this analysis contained no significant loadings. Jost's approach, aside from the fact that he used maladjusted and we normal *Ss*, is just the reverse of ours. He first determined the variables which differentiated his experimental and control groups and then subjected these to a factorial analysis. It was our intent first to determine the major axes along which our variables differentiated the *Ss* and then to analyze the variance of the significant variables to determine the basis of such variance.

TABLE III

SIGNIFICANT LOADINGS FOR FOUR FACTORS

'Control' Factor I			'Self-estimated Emotionality' Factor III		
No.	Loading	Variable	No.	Loading	Variable
2	.89	Ave. startle cond. R.Q.	24	.60	Time sample nerv. movements
4	.75	Ave. verbal cond. R.Q.	25	.92	Gen. neuroticism 'trait'
3	.55	Ave. motor cond. R.Q.	26	.68	Anxiety 'trait'
11	.62	Var. basal movement	28	.58	Inhibition 'trait'
13	.65	Movement inc. motor	29	.53	Visc. disturbance 'trait'
16	.73	Ave. basal movement	30	.58	Variability 'trait'
19	.61	Voice level R.Q. (Vb.)	11	.50	Var. basal movements
17	.57	Psychiatric rating			
'Arousal' Factor III			'Verbal Discharge' Factor IV (spurious?)		
No.	Loading	Variable	No.	Loading	Variable
5	.73	Ave. dist. cond. R.Q.	18	.72	Verbal R.T.
6	.86	Percent cond. inc. startle	21	.72	Verbal R.T.R.Q.
7	.86	Percent cond. inc. motor c.			
9	.90	Percent cond. inc. dist.			
8	.58	Percent cond. inc. verbal			

basal movement (*B.M.V.*) are present.[14] Thus a person ranking high on Factor I would be expected to show little variability in basal overt movement, effect a quick covert recovery from effects of stimulation and be rated as 'well adjusted.' All of these variables seem to be concerned with the efficient control of aroused bodily energies. Consequently we may for our purposes identify the first as an 'emotional control factor.'

The major significant loadings on the second factor are clearly concerned with 'percent conductance increment' or the extent to which any given individual is physiologically aroused by the experimental situations. The apparent anomaly of a high loading for 'average conductance R.Q.' during distraction is difficult to understand unless the distraction situation possessed a low stimulus value. In such a case only those individuals who were highly sensitive to the stimulus would have been displaced enough to necessitate the overt discharge of any tensions produced. In other words, any tension increment attributable to this situation would not immediately break over into overt activity (discharge) except in the case of those

[14] The only other variable significantly present in this factor is the increment in 'postural' movement which occurs during the motor discrimination situation. While this variable may appear on the surface to be unrelated to the others in the factor, it must be recalled that the adequate discharge of the energy aroused in this situation was *via* skeletal activity. It is not unreasonable to postulate that those individuals who discharged their neuromuscular tensions most efficiently in this situation indulged in more skeletal activity than those who took the less adequate paths of verbal, visceral, or ideational discharge (*cf.* 9).

Ss who possessed a high degree of reactivity. A high correlation would obtain between the extent of arousal to a mild stimulus and the conductance R.Q. to it. Because of the conductance increment loadings we may identify the second as an 'arousal factor.'

There is some question as to the identity of Factor III. The major variables with high loadings are self ratings on various aspects of emotionality ('general neuroticism,' 'nervousness,' 'visceral disturbance,' etc.). The principal exceptions are 'time sampling of nervous movements' and (possibly) 'variability of basal movement.' [15] We might, therefore, conclude that this as a factor represents *S*'s stereotype of how he reacts—a kind of 'self rated emotionality.' Certainly the factor is heavily weighted with pencil and paper tests.

Since the fourth factor has only two significant loadings, and since one of these variables is derived from the other, it appears safe to assume that the common factors present in the original matrix have been removed and that this factor is a 'specific.'

Discussion

If we take the point of view that homeostasis is a basic behavior process, it follows that the emotional response need be treated no differently than the maintenance aspects of more limited organ systems (Cannon, 1). As extended to cover 'total' behavior, the concept of homeostasis asserts that the organism is so structured that it reacts to stimulation in such a way as to restore a pre-existing constant state. It appears that the emotional response is an adjustment to a stimulus 'displacement,' involving at least two physiological components—'arousal' and 'recovery.' These components were measured to some degree in this study. While the results do not warrant definite conclusions, several suggestions seem to apply to the problem of isolating the emotional factors in personality structure.[16]

(1) Paper and pencil tests which purport to deal with emotional aspects of response appear unrelated to behavior observed during experimentally induced stimulus displacements. It is impossible to

[15] The fact that an almost significant loading on basal movement variability appears on Factor III along with the pencil and paper test of variability, might suggest that further exploration of personality structure would reveal a 'variability factor.' It is to be noted from Table II that galvanic basal variability (No. 1) correlated .60 with pencil and paper variability (No. 30). Further work in which many reactions to the same stimulus were obtained might reveal that the variability of the physiological measures is one of the most significant indices of the neurotic and emotionally unstable personality. Attention is called in this connection to Herrington's (9a) report of a correlation ($.51 \pm .23$) between a combined index of physiological variability and social indices of activity level.

[16] Personality structure is here defined as the resultant of the dynamic interaction of isolable propensities rather than the sum total of such 'traits.'

predict from questionnaire personality tests either the specific behavior or the general pattern which will occur in response to an actual emotional displacement. While the specific behavior is fortuitously determined by environmental circumstance, the underlying pattern seems to be a function of relatively stable aspects of the individual. Paper and pencil tests for predicting the general pattern of emotional responses to stress might well be validated against behavior indices of emotional homeostasis.

(2) Overt manifestations of responses to the displacements of emotional stress are only a part of the total behavior flux. Studies of emotional reaction must of necessity include covert as well as overt indices of behavior. Unless these covert manifestations are recorded, it is difficult to determine whether an individual is 'calm' in the given situation because it has no stimulus value to him or because, although internally aroused, he has inhibited the overt expression.

(3) When overt and covert responses are studied simultaneously, it appears that the factors differentiating individuals in emotionality are those of (*a*) arousal and (*b*) recovery. Recovery of internal equilibrium is, of course, related to the amount of arousal, and this is already covered in the R.Q. formula. But a far more important factor in recovery of emotional homeostasis is the *control* exercised over the overt expression of internally aroused excitation. We have therefore referred the second and most important emotionality measure to a 'control' factor.

The tacit assumption of most experiments in emotions has been that giving the same physical stimulus is an adequate means of keeping the emotional (arousal) value of that stimulus constant for all *S*s; the study of individual differences has been largely confined, therefore, to changes in overt expression. By such measures a person who reacts violently to a given electric shock or who is 'nervous' and 'jumpy' in a standardized stressful situation is rated as the more emotional. No such one-to-one correlation exists between the amount of internal arousal and the degree of externally observed 'emotionality.' Emotional expression should always be considered with respect to the extent of arousal. *The true emotionality continuum is that of the ratio of external expression to internal arousal*, and this varies from zero to unity.[17] That individual is physiologically most efficient who requilibrates by expressing aroused excitation in such a manner as to discharge the effects of stimulation most immediately and completely.

[17] The use of such a continuum presupposes that only the excitation aroused by a specific stimulus will be expressed. Actually, it often happens that in reacting to a specific stimulus, *S* expresses (releases) tensions persisting from previous stimulation. This would carry the continuum beyond unity and give an R.Q. greater than one.

Certain channels or patterns of expression are probably more effective than others in a given situation. Thus there will be situations in which ideo-motor or verbal behavior will more effectively discharge excitation than will gross muscular activity; other stimulus effects will be more readily equilibrated by gross bodily movements. Previous expressive habits of the individual are probably as much of a determinant of the discharge pattern and of its effectiveness as are the demands of the situation. Our measures have approached mainly the gross skeletal mechanisms of discharge; consequently they provide only a limited picture of the total pattern of expression. Further work should consider the type of discharge[18] in relation to stimulus arousal. In the present stage of our knowledge, the best measure of the neuro-muscular equilibrations of the intact organism appears to be found in the skin conductance R.Q.

Summary

Twenty-four male college students were subjected several times to each of four displacing stimulus situations. In addition every S filled out a battery of pencil and paper personality tests, was rated by trained clinicians on emotionality, and had a time sample taken of his nervous movements during a classroom situation. Thirty variables resulted from the study.

A factorial analysis of these variables yielded three orthogonal factors. Two of these have been tentatively identified as (1) control of the expression of energy, and (2) physiological arousal to stimulation. The third (3) has a large factor of self-rated emotionality and is apparently not related to behavior produced by the displacing situations.

The present status of the use of physiological measures of personality differentiation does not justify the drawing of any final conclusions. However, the results of this study do point in the direction of a fruitful field for future research.

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AN ELECTRONIC APPARATUS FOR TESTING FATIGUE BY THE VISUAL FLICKER METHOD

BY FRANKLIN HENRY

University of California, Berkeley

Simonson and Enzer (3) have reported that the critical fusion frequency of visual flicker is depressed 10 or 15 percent during the course of a working day, and that it is also depressed by insufficient rest. Lee (2) has found a depression as a result of several hours of truck driving. Baer and Braun (1) have found that the feeding of Vitamin B complex may produce a striking increase in the critical frequency. The apparatus used in these studies employed a motor driven sector disc for producing flicker in a constant light source.

In the apparatus diagrammed in Fig. 1, a neon glow lamp is caused to flash on and off at a rate determined by an adjustable resistor, and the relative duration of each flash is controlled by another resistor. The apparatus is silent in operation, direct reading, portable, and entirely assembled from commercially available radio parts. The rate of flashing changes continuously and instantly, and is standardized against the 60 cycle supply current by visual observation of Lissajous figures appearing on the screen of a small cathode ray oscilloscope tube.

Preliminary experiments by Dr. James A. Hamilton and the writer place the average monocular critical fusion frequency at about 45 cycles, which is fairly close to the mean reported by Simonson and Enzer, but somewhat higher than the averages found in the other studies cited. The standard deviation of the mean of ten successive trials seems to be about 0.1 cycle, and the split-half reliability is $r = .99$ ($\sigma_{\text{dist.}} = 2.8$, $N = 16$). With a 24 hour period between test and retest, the coefficient drops to $r = .91$. There is a correlation of $r = .95$ between the two eyes. The results of Simonson and Enzer (3) have been confirmed with the new apparatus, and there is some indication that physical exercise produces an immediate temporary increase in the critical rate followed by a depression.

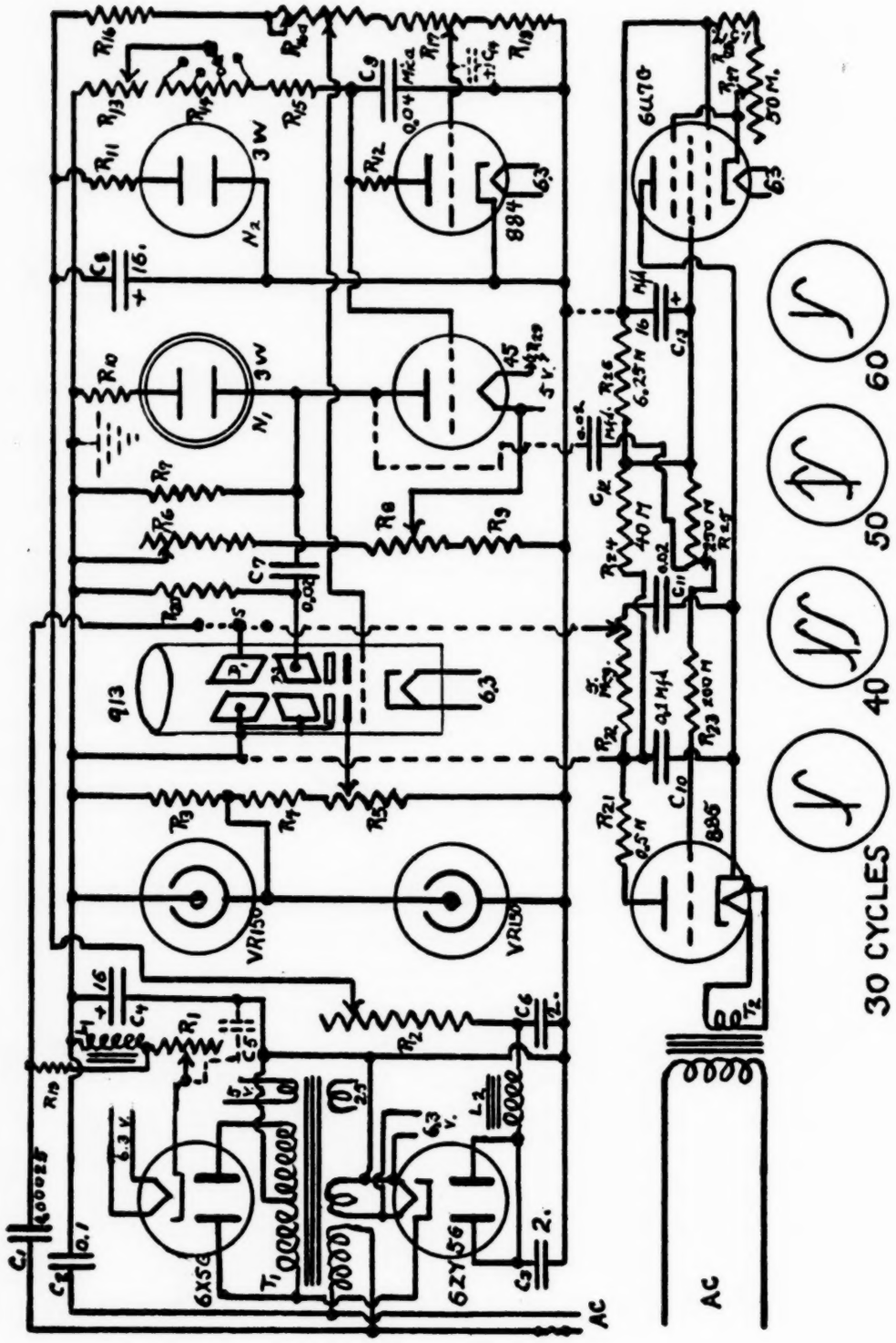
The flicker lamp (N_1) is a 3 watt neon glow lamp having an evenly illuminated 1 inch circular plate that gives a light of 7.5 to 8 foot candles at a distance of 1 inch when the flash duration is 2/3 cycle. It is viewed at a distance of one foot from an aperture of 0.197 inch (5 mm) that is placed 1 inch from the illuminated plate. The duration is approximately a linear function of the setting of R_8. When

the adjustable tap of this resistor is 1000 ohms above R_9 the duration is 2/3 cycle, and drops to 1/3 cycle when it is moved up to 2500 ohms (R_6 being adjusted to give 13.5 Ma. through the 45 anode at a flicker rate of 60 per second).

Fine adjustment over a 7 cycle range of the flash frequency is made with R_{13}, and coarse adjustment by 2 cycle steps is made on R_{14}. The latter is a 17 point shorting type switch with a 0 to 16 dial controlling 16 resistor units of 20,000 ohms each. Inexpensive 'Bradley' type units are satisfactory for R_{14}, but their resistance should be tested, and they should be serially arranged in such a way that their errors will not be cumulative. Resistors R_{13}, R_{14} and R_{15} and capacitor C_9 should be mounted in a 3/4 inch closed wooden box that is separated by an air gap from the box containing other parts of the apparatus, in order to reduce frequency drift due to temperature change. The two R_{16} resistors, and also R_{17} and R_{18}, may be in this small separate box too, but should be ventilated and separated from the frequency control resistors by a partition. The only external controls on the apparatus are the frequency adjustors R_{13} and R_{14} and the calibrator R_{17}.

It is necessary to make certain initial adjustments if the instrument is to be direct-reading. With R_{13} at mid-point and R_{14} at 15 (the minimum setting being 16), R_{17} is set for a frequency of 60 cycles. R_{14} is then increased about 15 steps (making fine adjustment with R_{13}) until the 30 cycle setting is located. If more or less than 15 steps are required for the 30 cycle change, R_{17} is changed (compensating with R_{13} to secure 60 cycles with R_{14} at 15) until a range of exactly 30 cycles per 15 steps is secured. The resistance necessary for this adjustment of R_{13} is estimated, and an auxiliary resistor of this size is permanently inserted in series with it. The normal position of the calibrator R_{17} is then established at mid-point by inserting a 250 or 500 ohm resistor above or below it if necessary, or by adjusting the upper tap of R_{16a}. The mid-point voltage of R_{17} in the present apparatus is approximately 16. It should be noted that the range in cycles per step can also be increased by 'padding' C_9. The capacitor C_{14} may be required to prevent 'lock-in' at 30 and 60 cycles if filtering is otherwise inadequate.

The neon lamp N_2 is of the same type as the flicker lamp N_1, but is here used as a voltage regulator. These lamps as commercially available have an internal resistor within the brass base that must be shorted out in both. By sawing into the base just opposite the solder mark at the base-glass junction, a resistor terminal is exposed which may be grounded to the base. The resistor R_2 should be adjusted to give 9 or 10 Ma. through N_2, realizing that any change will affect the setting of R_{17} and may require compensation on the upper tap of


30 CYCLES
40
50
60
AC
AC
6XSG
6ZY5G
VR150
VR150
9D4
6L7G
884
9J3
3W
3W
45
5Y3G
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R_{16a} to maintain a current of 3.1 Ma. through it. The optimum resistance of R_{11} depends on the characteristics of the transformer and the 884 tube; if it is correct, the flicker rate will remain stable even if the supply voltage varies considerably. In the experimental model, a resistance of 1000 ohms resulted in just noticeable over-regulation, and 3000 ohms under-regulated to a slight extent.

Resistor R_1 should be adjusted to give a current flow of 15 or 20 Ma. through the V R 150 voltage regulator tubes; if this setting leaves less than 1000 ohms in the circuit an input capacitor C_5 of 1 or 2 mfd. will raise the voltage so that more resistance can be used. R_5 and the second clip on R_{16a} control the beam focus and intensity of the cathode ray tube; the beam should be reduced as far as convenient in order to prevent deterioration of the fluorescent screen. Changing the size of R_{19} will control the deflection produced from the 60 cycle supply line that is used as a frequency standard. At a flicker frequency of 60 per second, the connections shown will produce an ogive-like figure with a fixed vertical line that disappears in the region below the curve, and at 30 cycles a similar figure with the vertical line extending through the figure. The 45 cycle figure is similar to the 30 with the exception that it is intermittent. This is the figure

---

Capacitors:

C_2C_{10} = .1 mfd. 600 V.
$C_3C_5C_6$ = 2 mfd. 600 V.
$C_7C_{11}C_{12}$ = .02 mfd.
$C_4C_8C_{13}$ = 16 mfd. 450 V. Electrolytic
C_{14} = 10 mfd. 25 V. Electrolytic
C_1 = .00025; C_9 = .04 mfd. mica

Potentiometers:

R_{13} = 70,000 ohm W.W. 4 W.
R_{17} = 500 ohm W.W. 4 W.
R_5 = 100,000 ohm carbon V.C.
R_{22} = 5 megohm carbon V.C.
R_{25} = 250,000 ohm carbon V.C.
R_{27} = 50,000 ohm carbon or W.W.

Adjustable 50 W. resistors:

R_1 = 5,000 ohms
R_2 = 30,000 ohms
R_6 = 15,000 ohms
R_8 = 4,000 ohms
R_{16a} = 10,000 ohms

Fixed 10 W. resistors

R_7 = 7,500 ohms
R_{11} = 2,000 ohms
R_{16} = 10,000 ohms

Fixed 10 W. resistors

R_{18} = 6,000 ohms
R_{29} = 1.7 ohms (or 2 ohms adj.)
R_9 = 3,000 ohms 20 W.

Chokes:

L_1L_2 = 30 h. 75 Ma.

Fixed 1 W. resistors:

R_3R_{23} = 200,000 ohms
R_4 = 100,000 ohms
R_{10} = 200 ohms
$R_{12}R_{21}$ = 500 ohms
R_{14} = 20,000 ohms (16 required)
R_{24} = 40,000 ohms
R_{26} = 6,250 ohms
R_{28} = 1,500 ohms
R_{19} = 1 megohm
R_{20} = 2 megohms
R_{15} = $\frac{1}{4}$ megohm W.W. precision type

Transformer:

T_1 = 700 V.C.T. 50 Ma., 6.3 V. 2.5 A, 5 V. 2 A, 2.5 V. 1.5 A

used routinely as a working standard. A double ogive is produced at 40 cycles, and one and one-half ogives at 50. These figures are illustrated at the bottom of Fig. 1. Their occurrence as a function of the dial readings of R_{13} and R_{14} may be plotted as a calibration curve, which will be linear if the resistors are accurate. The dial of R_{13} is calibrated by the substitution method, interpolating between the 2-cycle points obtained by altering R_{14}.

If an accurate adjustment of the flash duration is required, the simplest procedure is to measure the 'on' and 'off' portions of the trace on an ordinary radio repairman's oscilloscope attached across the resistor R_{10}. If such an instrument is not available, the auxiliary circuits shown in the lower part of Fig. 1 will convert the 913 tube into a linear sweep oscilloscope. The sweep rate is controlled by R_{27} and C_{10}; R_{22} adjusts the sweep amplitude and R_{25} (which should be kept as low as possible) controls the lock-in required to hold the image stationary. T_2 is of course not required if T_1 is provided with the extra 2.5 winding shown in the diagram. The cathodes of both the 884 and 885 tubes should return to the mid-tap of the filament windings if the transformer has provision for this, and the 6.3 mid-tap (rather than one side as shown in Fig. 1) should be connected to the common negative line. These gas-triodes do not operate consistently unless the filaments are kept at approximately cathode potential. They also require a current limiting resistor of 0.1 or 0.2 megohms in series with the control grid (unintentionally omitted in the diagram of the 884 tube connections).

A number of modifications of this apparatus are possible. For example, the cathode ray tube could be replaced with a 6AB5 or 6E5 'magic eye' tube which would give visual beats for frequency standardization if the grid was excited from both C_1 and C_7. R_{19} and R_{20} would in this case be volume controls whose variable arms would be connected to C_1 and C_7. It is quite possible that the Argon-filled 2A4G gas triode would give better frequency stability than the 884 type. This alteration would require circuit adjustments. The mica capacitor C_9 could be replaced with a paper dielectric capacitor at some sacrifice in stability. The two V R 150 tubes could be replaced with a series of five or six neon glow lamps, with internal resistors shorted. In a preliminary form of the apparatus, the neon tube N_2 was used in place of the 884 tube, and was coupled to the grid of the 45 tube with a voltage amplifier. The 6ZY5G rectifier and associated resistors were not used, and C_9 had a different capacity. In another modification the 884 'saw tooth' oscillator and 45 tube was replaced with a conventional L-C oscillator, and a constant series potential limited the illumination of N_1 to a single plate. The flash duration of N_1 was determined by the amplitude of the oscillator

output. All of these modifications appear to have certain advantages in frequency stability, portability and simplicity of operation as compared with the older motor driven disc type of flicker apparatus. They are not, of course, as flexible with respect to light-color, yielding only orange and (with filters) red and yellow, but for many purposes this is no disadvantage.

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